Regulating Energy between Main Supply and Solar Energy Using Power Electronics Devices

by

Muhammad Nizar Bin Jamaludin

Project Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical and Electronics Engineering)

DECEMBER 2004

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

(Mr Taib Bin Ibrahim)
Main Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH PERAK
DECEMBER 2004

CERTIFICATION OF ORIGINALITY

This is to verify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD NIZAR JAMALUDIN

ABSTRACT

The project title is *Regulating Energy between Main Supply and Solar Energy Using Power Electronics Devices*. The aim is to design a regulating system between main supply and solar energy using power electronic devices. The study explored the implementation of several type of power electronics circuits such as rectifier circuit, filter circuit, regulator circuit and switching circuit.

In the project process, Multisim2001 have been used as the simulation tools. Simulation process is a very important in order to test the operation of circuits and also to integrate between circuits.

Ultiboard is another software that is used in this project. The software used to convert simulated circuit into PCB circuit. The process of conversion into PCB is done in the lab.

For this project, the author has successfully produced the prototype for 15 V. The prototype has been tested and it works well. Besides, simulations for a circuit that can withstand 240 V also have been successfully simulated.

ACKNOWLEDGEMENT

I would like to express my greatest gratitude to my supervisor Mr. Taib B. Ibrahim for his invaluable advice and supervision throughout the progress of the research. Thanks for the time, guidance and patience.

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I wish to dedicate this work to my parents Mr. Jamaludin B. Hasan and Mrs. Wan Zaharah Bt. Haji Abdullah, my brothers and sisters, and my fellow families for their support, encouragement and understanding throughout the course of this project.

I wish to thank my entire colleagues who have been together contributing ideas and knowledge throughout the research study.

Finally, this work is also dedicated to my sponsor, PETRONAS that have been sponsoring me for my studies in Universiti Teknologi PETRONAS.

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ABBREVIATIONS AND NOMECLATURES

FYP	Final Year Project
TNB	Tenaga Nasional Berhad
AC	Alternate Current
DC	Direct Current
PLC	Programmable Logic Circuit

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Regulating between the main power supply with other backup energy is getting common nowadays. Back in August 1996, there was a case where the main power supply for Peninsular of Malaysia has broke up. Because of the problem, many small factories have to stop their production thus creating losses. Tenaga Nasional Berhad (TNB) has to pay the compensation for the losses. We can see how important to have a backup energy in case of any main power brake up.

The aim of this project is to come out with a system that can regulate main power supply with backup energy, using power electronic devices. The backup energy that will be used is the solar energy. The solar energy is chosen because it is free ad have a big potential to be develop as the main energy. In a long term, using solar energy will definitely reduce the cost of energy consumed, thus saving a lot of money.

The devices includes in the circuits are resistors, inductors, capacitors, transistors and switches. The circuit that will be design should be able to choose for the best power energy available; either the main power supply or the solar energy and produce it as the output.

1.2 Problem Statement

Nowadays, the backup power supply is required to be more efficient due to unreliable main supply. The common phenomenon is breakdown of the main supply that is also called as blackout. Because of this problem, backup power supply is needed. The backup would be used when the main power supply is not functioning.

The need for development of free natural energy is also to be addressed. In this project, solar energy is used as the backup energy. The solar energy will be produced by using photovoltaic cell and it will be stored in battery. The usage of solar energy should be develop because it is one of a natural energy and totally free.

1.3 Objective and Scope of Study

The main objectives of the project are:

i. To study about all of the components involved in this project including circuits functionality and also production of solar energy.
ii. To design a circuit that can regulate between main supply and solar energy using power electronics devices.
iii. To produce a prototype as the project model.
iv. To enhance the system by designing a system that capable to operate under 240V.

The scope of the study will be limited to:

i. Conducting literature review on rectifier circuit, filter circuit, regulator circuit, switching circuit, solar panel and solar battery.
ii. Produce and simulate circuit created using Multisim 2001.
iii. Conducting a laboratory testing for each circuit and the solar system.
iv. Conducting literature review on power electronic devices that can withstand 240V.

CHAPTER 2

LITERATURE REVIEW AND THEORY

This project actually acquires the student to construct the hardware and study about the implementation of power electronic devices in a power regulating circuit. The overall p roject can be divided into four main circuits. The circuits are rectifier circuit, filter circuit, regulator circuit and switching circuit. All of these circuits are interrelated, thus the design of each circuit has to be integrated with each other. Others, the project also contained the implementation of s olar p anel a nd s olar b attery i n p art o f t he s olar system.

2.1 Design Concept

Design concept of the project is shown in Figure 2.1.

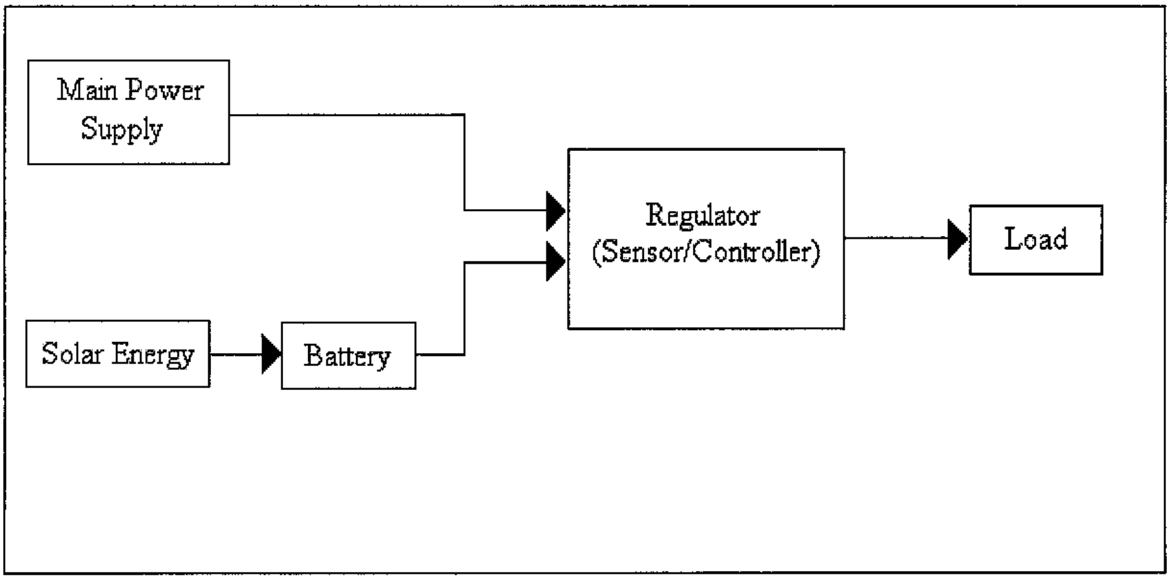


Figure 2.1: Project Block Diagram

This block diagram shows the basic concept of the regulating system. There will be two inputs that is main power supply and solar energy. The solar energy will be charged and stored in a battery in order to increase the voltage. These two inputs will be sent to the regulator. The regulator acts like a switch that can choose automatically either to use the main power supply or the solar energy as the power source to the load. The input power will be chosen based on the availability of input supply. The output of the regulator will be connected to the load.

The AC signal of main supply has to be converted to DC signal in order to compare the power with the input from the solar system (switching implementation). To do the conversion, several circuits are implemented that are; rectifier circuit, filter circuit and regulator circuit.

2.2 Circuits

2.2.1 Rectifier Circuit

Basically, a rectifier circuit is used to convert AC voltage to DC voltage. Figure 2.2 shows the rectifier circuit. The output resulting from a rectifier is a pulsating DC voltage and not yet suitable as a battery replacement (not a pure DC voltage). Such a voltage could be used in, such as a battery charger, where the average DC voltage is large enough to provide a charging current for the battery.

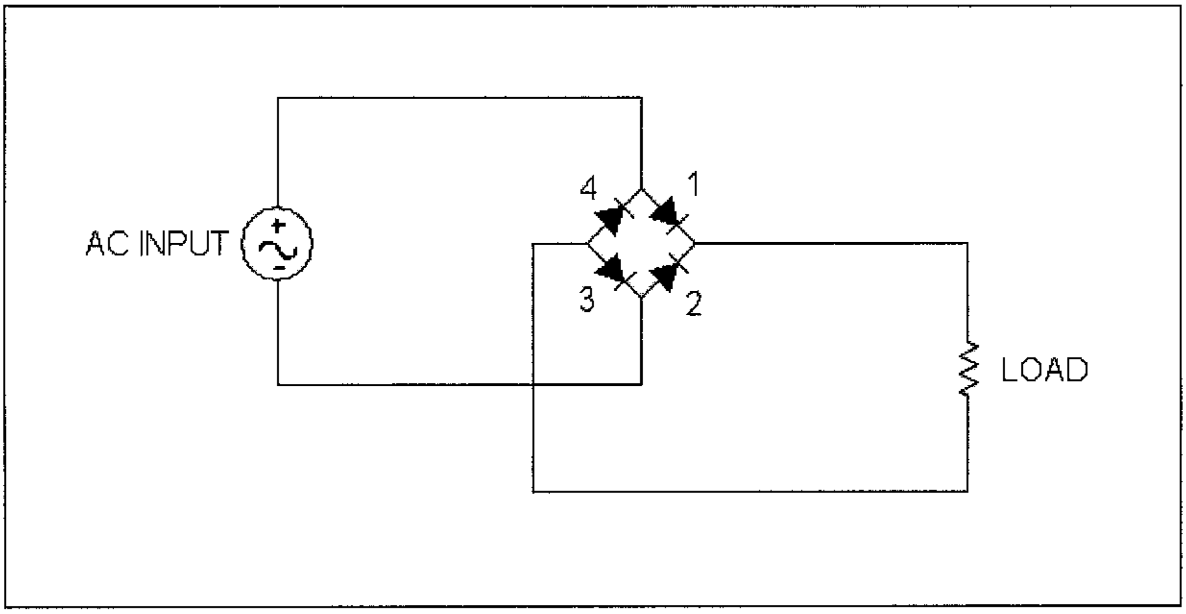


Figure 2.2: Rectifier Circuit

2.2.2 Filter Circuit

For DC supply voltages, as those used in a radio, stereo system, computer and so on, the pulsating dc voltage from a rectifier is not good enough. A filter circuit is necessary to provide a smooth DC voltage [1]

For the filter circuit, a capacitor filter circuit is been used. The purpose of the capacitor filter is to pass most of the dc components while attenuating (reducing) as much the AC component as possible. Figure 2.3 shows the concept of the filter circuit.

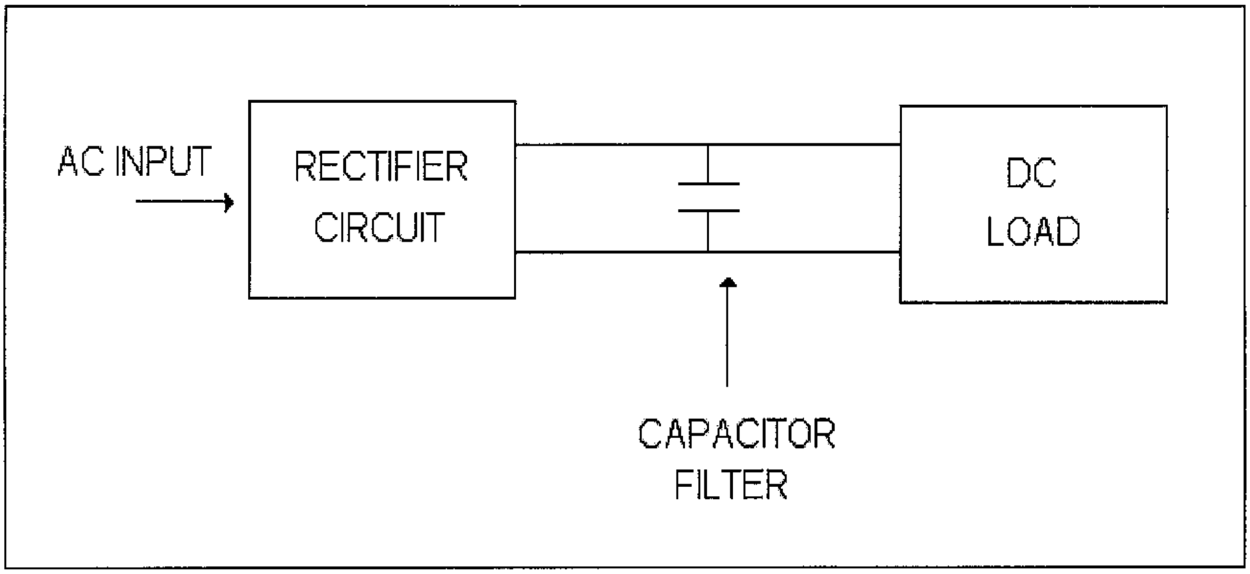


Figure 2.3: Concept of Filter Circuit

2.2.3 Regulator Circuit

A voltage regulator circuit provides a constant DC output voltage that is essentially independent of the input voltage, output load current and temperature [1]. The voltage regulator is one part of a power supply. Its input should come from the filtered output of a rectifier derived from an AC voltage (main power) or from a battery (solar energy). Figure 2.4 shows a regulator circuit. Figure 2.5 shows the basic components in a block diagram of a series type regulator circuit.

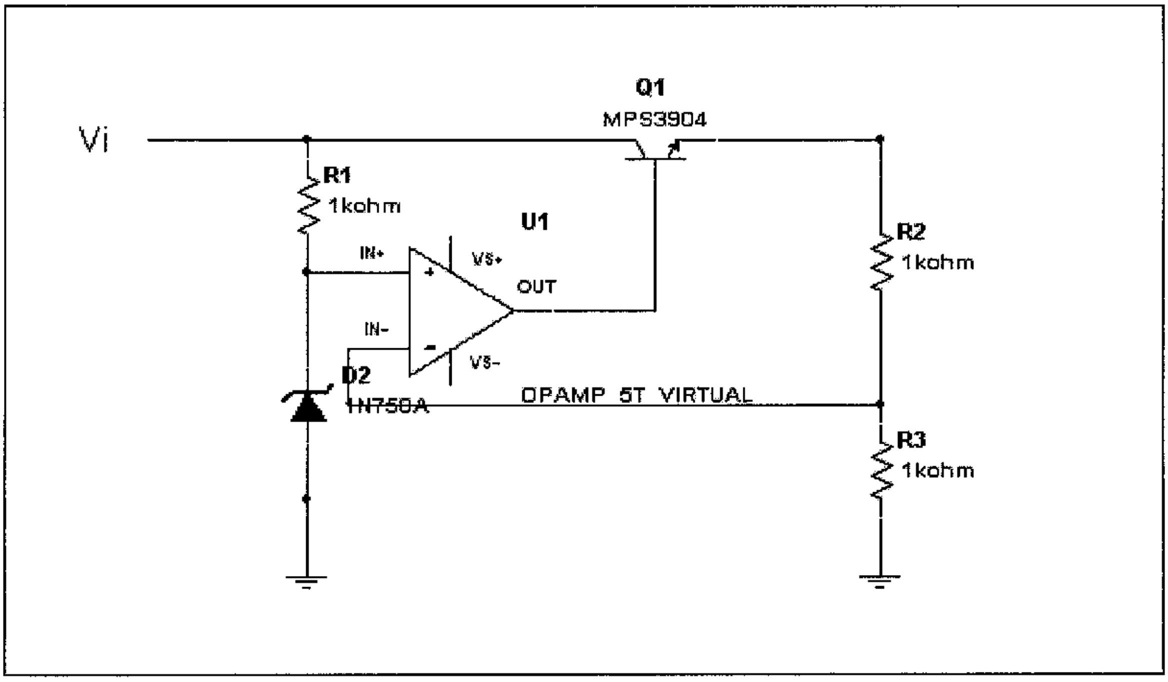


Figure 2.4: Regulator Circuit

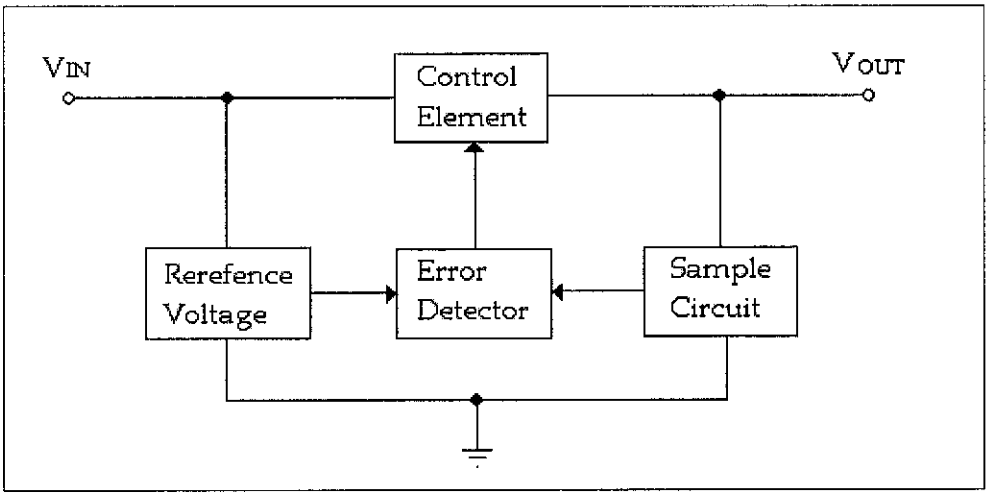


Figure 2.5: Series Regulator Block Diagram

The control element is in series with the load between the input and output. The output sample circuit senses a change in the output voltage. The error detector compares the sample voltage with a reference voltage and causes the control element to compensate in order to maintain a constant output.

In other words, the operation of regulator circuit is as follows:

i. If the output voltage decreases, the increased base-emitter voltage causes the transistor to conduct more, thereby raising the output voltage – maintaining the output constant [1].
ii. If the output voltage increases, the decreased base-emitter voltage causes the transistor to conduct less, thereby reducing the output voltage – maintaining the output constant [1].

By combining all of the three circuits that are rectifier, filter and regulator circuit, a approximately smooth DC voltage can be obtained from the main supply. Figure 2.6 shows the block diagram for these three circuits.

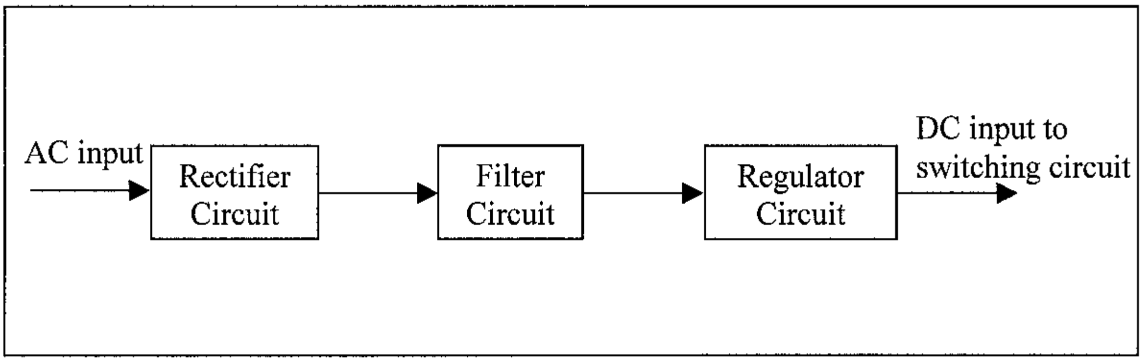


Figure 2.6: Block Diagram of the Related Circuit

Figure 2.7 below shows the combination of rectifier, filter and regulator circuits.

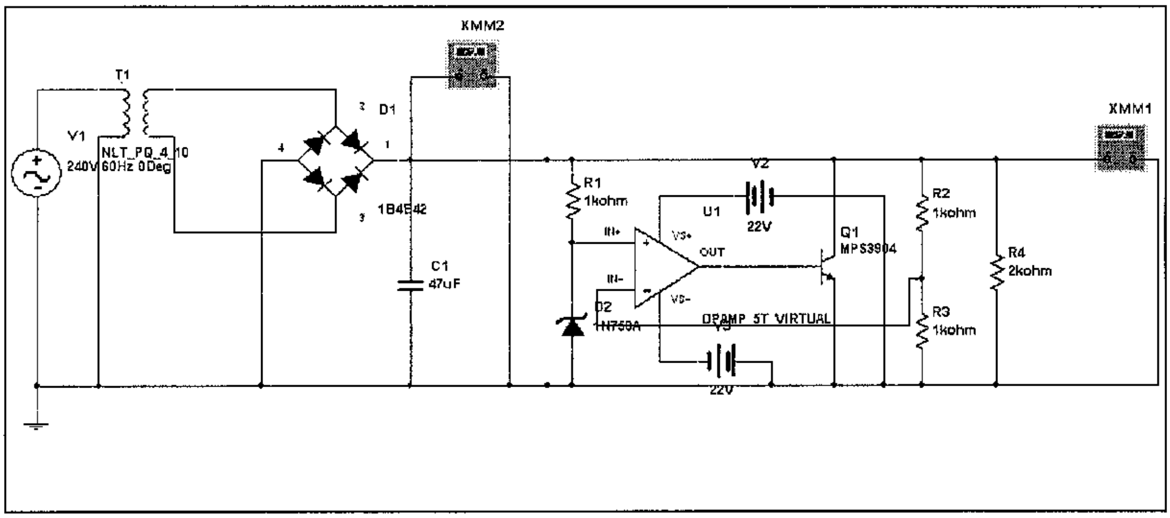


Figure 2.7: Combination of Rectifier, Filter and Regulator Circuits

2.2.4 Switching Circuit

Basically, the switching circuit acts as a switch for a backup power supply. Once power breakdown occurs, the switching circuit will act to switch from the main supply to the solar energy (backup energy). In this circuit, two transistors, together with one zener diode, two capacitors and four resistors are used.

Figure 2.8 shows the complete circuit of switching circuit. The switching mechanism is based on the application of transistor.

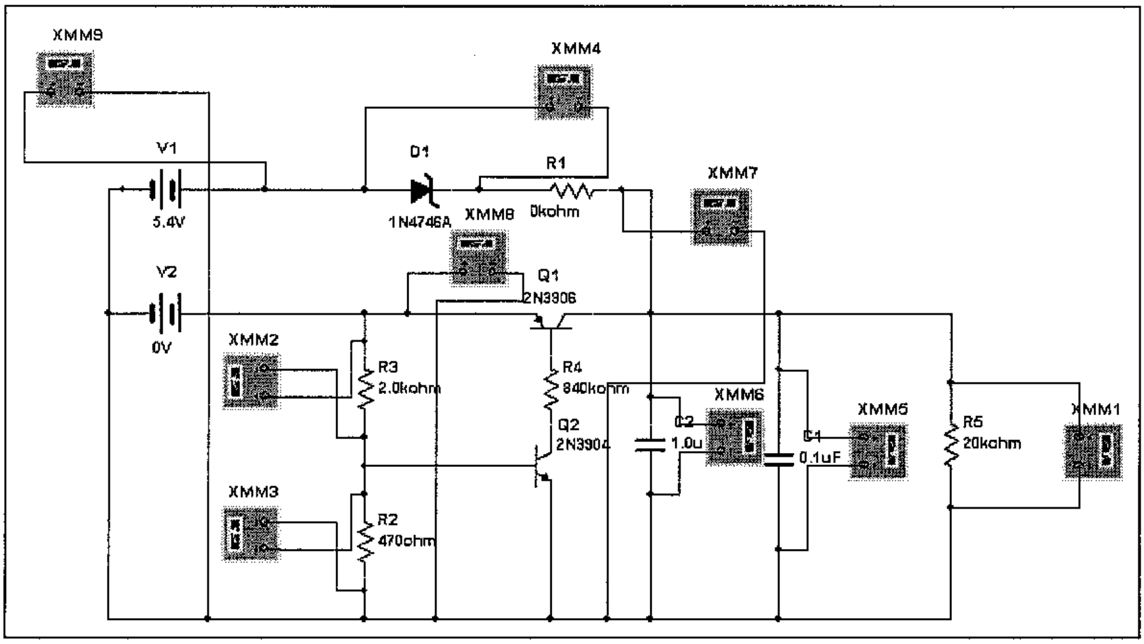


Figure 2.8: Switching Circuit

From the circuit, 5.4V (V1) acts as the voltage supply while the 5V (V2) in as the backup voltage. As long as there is enough power supply to the main input (V1), both transistor are biased and filter out while blocking the input from the backup voltage (V2). The output was connected with a load resister to determine the voltage produced.

2.3 Design Concept for Production of Solar Energy

Actually, solar energy can be treat normal voltage and can be store into battery same as the application of charging rechargeable battery. The different is just the voltage source come from the sun. Block diagram below shows the interconnection between each components of the solar energy system.

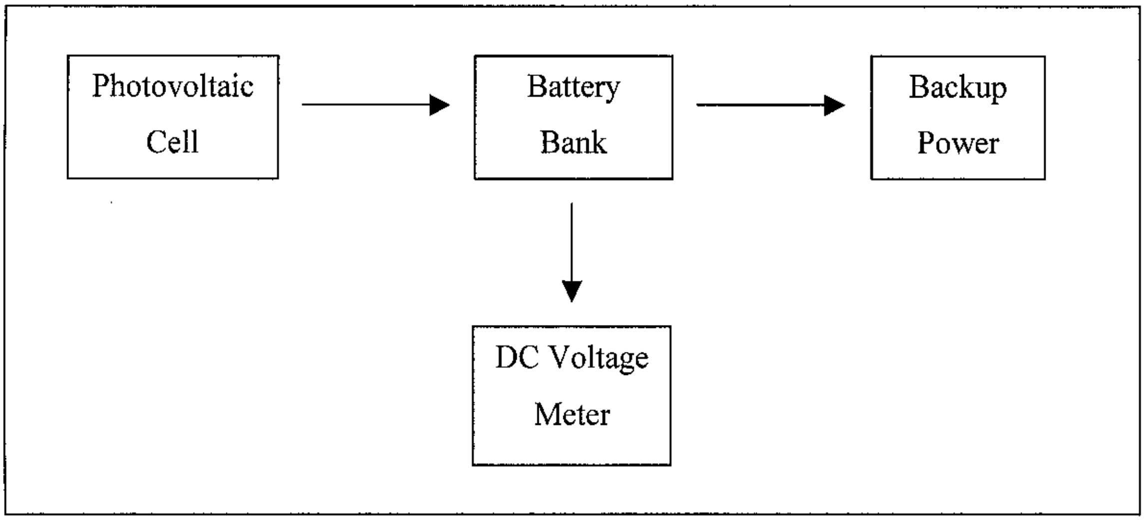


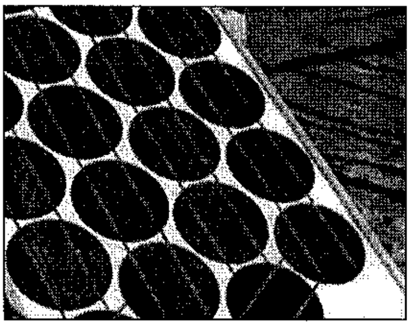
Figure 2.9: Block Diagram for Production of Solar Energy

2.3.1 Photovoltaic Cell

Photovoltaic cells are devices which convert solar energy directly into electricity, either directly via the photovoltaic effect, or indirectly by first converting the solar energy to heat or chemical energy. The most common form of photovoltaic cells are based on the photovoltaic (PV) effect in which light falling on a two layer semi-conductor device produces a photovoltage or potential difference between the layers. This voltage is capable of driving a current through an external circuit and thereby producing useful work.

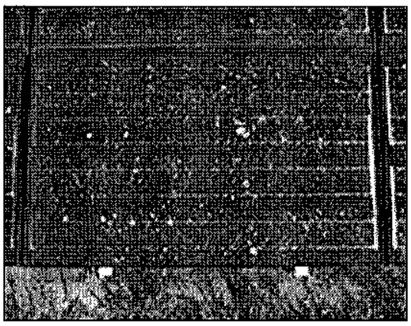
Silicon photovoltaic cells are made using single crystal wafers, polycrystalline wafers or thin films. Single crystal wafers are sliced from a large single crystal ingot which has been grown at around 1400 °C, which is a very expensive process. The silicon must be of a very high purity and have a near perfect crystal structure. Polycrystalline wafers are made by a casting process in which molten silicon is poured into a mould and allowed to set. Then it is sliced into wafers. It is significantly cheaper to produce, but not as efficient as monocrystalline cells. The lower efficiency is due to imperfections in the crystal structure resulting from the casting process. Amorphous silicon, one of the thin film technologies, is made by depositing silicon onto a glass substrate from a reactive gas such as silane (SiH_4). This type of photovoltaic cell can be applied as a film to low cost substrates such as glass or plastic. The advantages of it include easier deposition and assembly and it have the ability to be deposited on inexpensive substrates or building materials. Figure 2.10 shows the different types of photovoltaic cells [6].

Photovoltaic cells consist of two types of material, often p-type silicon and n-type silicon. Light of certain wavelengths is able to ionize the atoms in the silicon and the internal field produced by the junction separates some of the positive charges ("holes") from the negative charges (electrons) within the photovoltaic device. The holes are swept into the positive or p-layer and the electrons are swept into the negative or n-layer [6]. Although these opposite charges are attracted to each other, most of them can only recombine by passing through an external circuit outside the material because of the internal potential energy barrier. Therefore if a circuit is made power can be produced from the cells under illumination, since the free electrons have to pass through the load to recombine with the positive holes. The amount of power available from a PV device is determined by the type and area of the material, the intensity of the sunlight, and the wavelength of the sunlight [6].



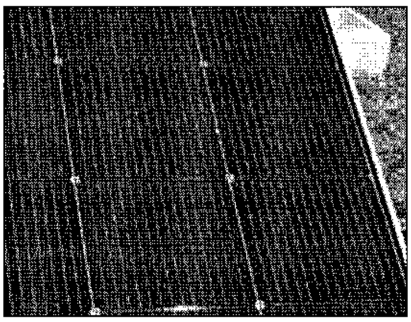
(a)

a) Single Crystal Photovoltaic Cell



(b)

b) Polycrystalline Photovoltaic Cell



(c)

c) Amorphous-Si Photovoltaic Cell

Figure 2.10: Different Type of Silicon Photovoltaic Cells

Figure 2.11 show the photovoltaic cell that is used to generate the solar energy for this project. From the specification given, the black plastic frame at the solar panel used to provides protection to the back and edges of the panel. The two mounting holes made easy for any installation. This module is suitable for applications where there is a requirement to charge both nickel cadmium and small dry fit batteries.

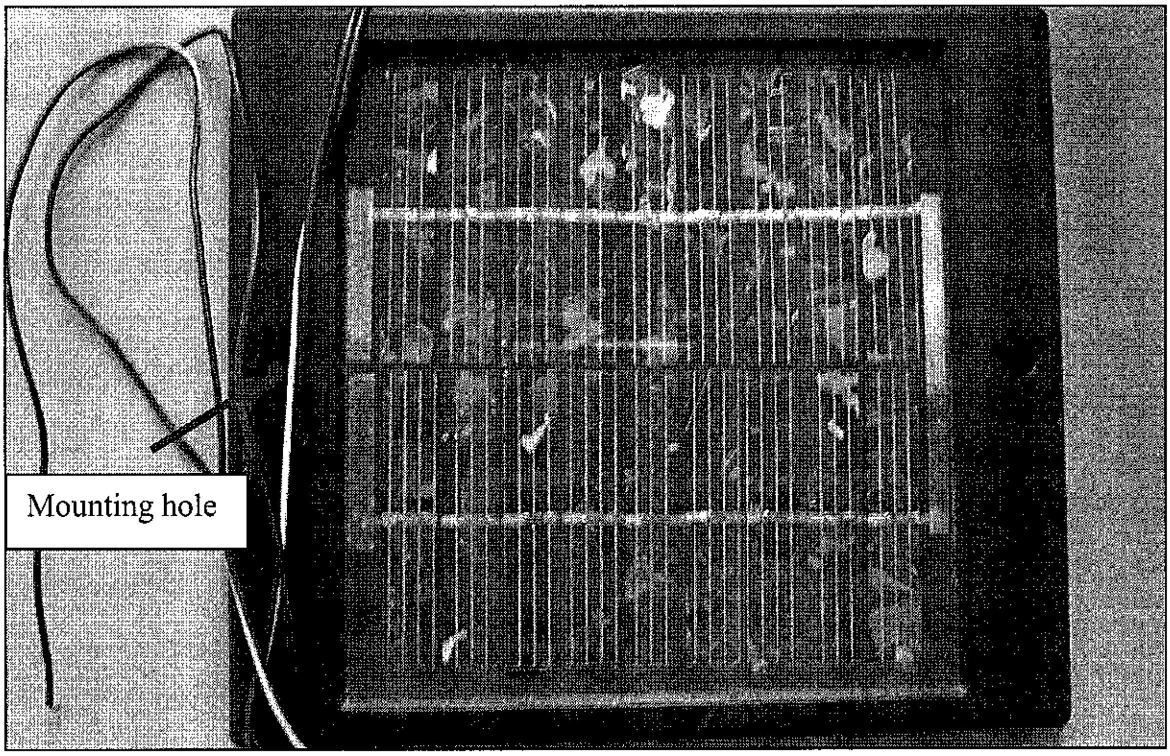


Figure 2.11: Polycrystalline Photovoltaic Cell

The specification below is tested at standard test conditions (STC) which are: illumination of $1kW/m^2$ (1 Sun), spectral distribution 1·5 and solar cell temperature 25°C.

Table 2.1: Polycrystalline Photovoltaic Cell Technical Specification

TECHNICAL SPECIFICATION		
Output power (min.)	0·446W	1·01W
Load voltage	3·3V	7·5V
Open circuit voltage	4·6V	10·3V
Load current	150mA	150mA
Short circuit current	160mA	160mA
Temp. coeff. V/°C	-16mV	-37mV
Temp. coeff. I/°C	0·15mA	0·15mA

2.3.2 Solar Batteries

Batteries are used for a wide variety of services throughout technology today. To study battery operation and characteristics, a few terms that are used with batteries must be understood:

1. Voltaic cell - The term voltaic cell is defined as a combination of materials used to convert chemical energy into electrical energy. A voltaic or chemical cell consists of two electrodes made of different types of metals or metallic compounds placed in an electrolyte solution.

2. Battery - A battery is a group of two or more connected voltaic cells.

3. Ampere-Hour - An ampere-hour is defined as a current of one ampere flowing for one hour. Ampere- hours are normally used to indicate the amount of energy a storage battery can deliver.

There are three general types of batteries, the "starting battery" that is generally a sealed battery and is used in your car, the "RV/Marine Deep Cycle" and the "True Deep Cycle".

Cranking - This battery is designed to start your engine and is not meant to be deeply discharged and recharged for many cycles. It is not appropriate as a "house" type battery

RV/Marine "deep cycle" - This sealed battery was designed for multiple task use in the marine environment. It is basically a hybrid between the "Cranking" battery and "True Deep Cycle" which we will get into next. RV/Marine "deep-cycle" batteries are considerably shorter lived, and as the "house" battery in an RV will last about 2 to 3 years. In terms of cycles they can deep cycled 300-400 times before they need replacing.

True Deep Cycle - Typically, two 6 volt golf cart type batteries are tied together for a 12 volt system. There are also true deep cycle 12 volt batteries in one case. Actual life can be 2 to 8 years depending on maintenance. These batteries are designed for deep cycling and being recharged.

CHAPTER 3
METHODOLOGY AND PROJECT WORK

Methodology and procedure is important to ensure that the project is done correctly and good result can be obtained. Emphasize is given to the detail study on the related circuits and solar system. The methodology and procedure to conduct the project is divided into three main parts:

3.1 Literature Review

Information regarding the circuits and solar system are gathered from respective books, journals and thesis developed by external and internal parties. All of the information are skimmed and selected based on importance and relevancy. The relevant information and example data are studied thoroughly.

3.2 Software Simulations

Simulation works are done during the process of designing and creating circuits for the project. Multisim 2001 is used as the simulation tool. By using the software, circuit can be created and simulated, basically to determine the output and detect any error. By doing this, the cost of creating the circuit would be reduced because it does not involved any hardware to be used. The circuits can be changed frequently until the desired output required.

After all of the circuits have been finalized, software called Multisim Ultiboard is used. Ultiboard is one of the industry's leading PCB layout tools and offers many advantages over other layout programs, including trace width optimization synchronized with Multisim simulation. PCB board is produced as the prototype of the project.

3.3 Laboratory Work

Laboratory work covers the preparation of experiment setup for both circuits and solar system. For the circuits, it is first setup on a breadboard as shown in Figure 3.1. Using this method, it is easy to modify the circuits during the setup process. For testing purposes, two power supply and digital multimeter is used.

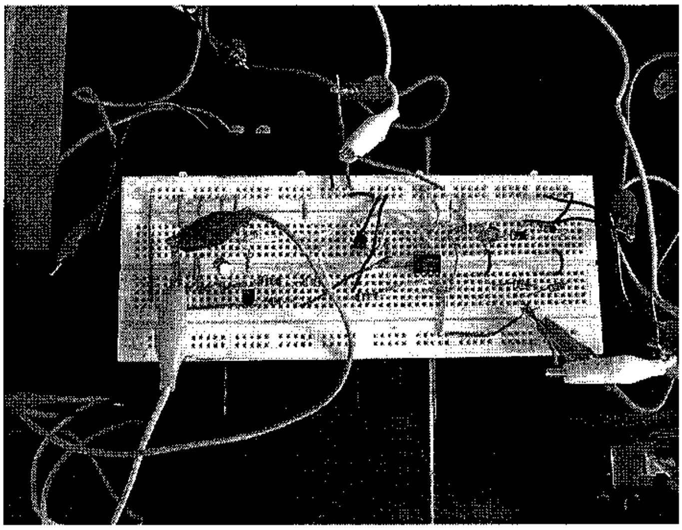


Figure 3.1: Circuits in Breadboard

For the solar system part, first of all, the support or frame for the photovoltaic cells is constructed. Twenty pieces of solar panel are screwed to the support as shown in Figure3.2. The wires of each solar panel are assembled in order to connection the solar panel together.

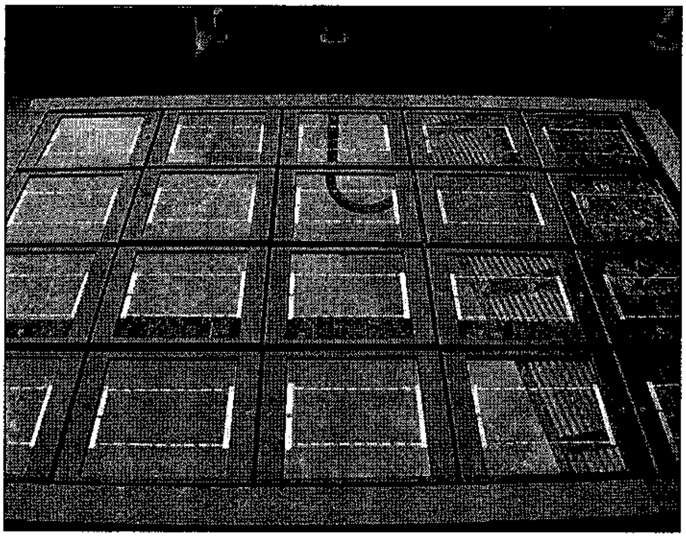


Figure 3.2: Photovoltaic Cells in the Frame

Next, the solar panels are connected to the solar battery trough a solar control circuit. This control circuit is essential because it will monitor the flow of the current in and out the solar battery. Basically, it will ensure that the battery is not over charge and also over discharge. This will protect the solar battery and increase it lifespan. Figure 3.3 shows the connection between photovoltaic cells, solar battery and control circuit.

After each part has been successfully constructed, the whole system is then constructed. Several modifications are done in order to get a better result. At the end, the system has been successfully created and tested working.

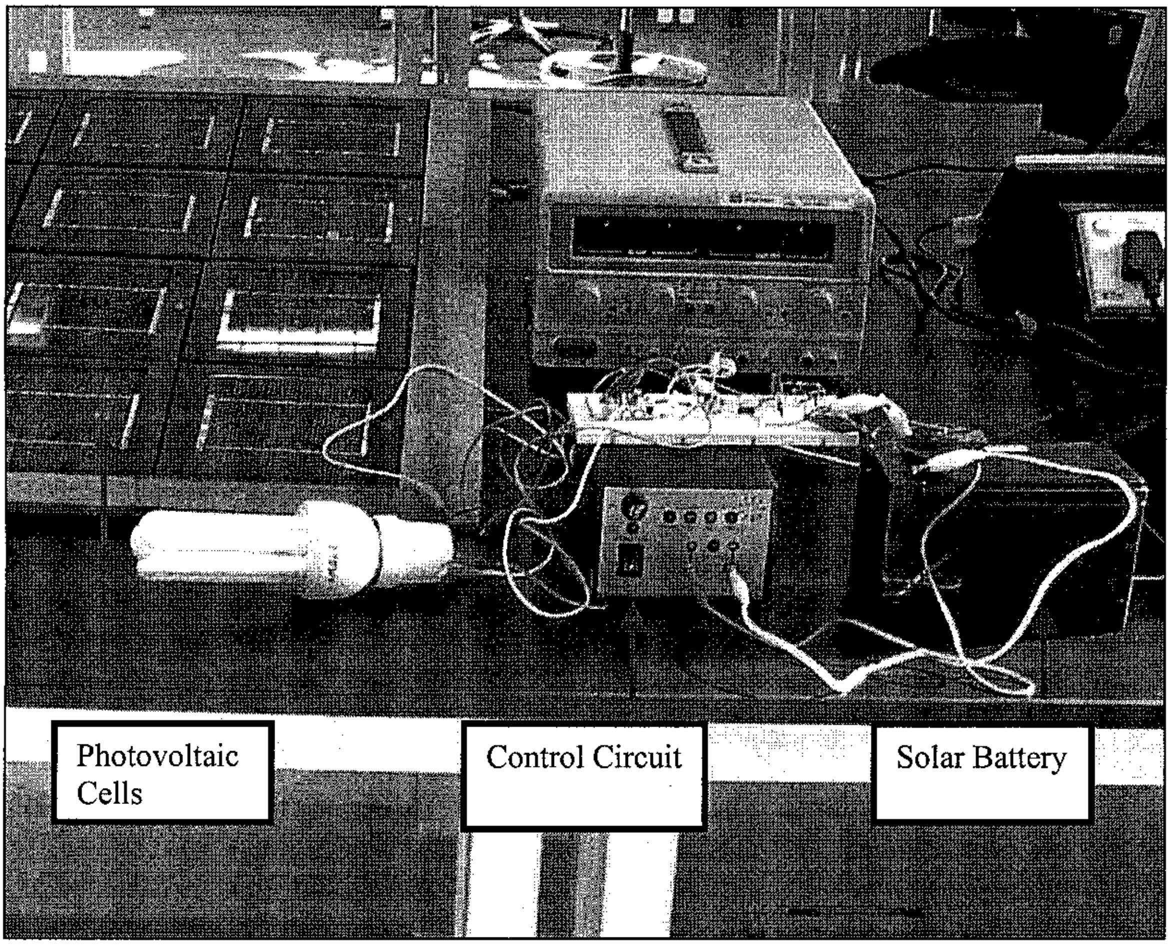


Figure 3.3: Photovoltaic Cells, Control Circuit and Solar Battery

Figure 3.4 shows the flow chart of procedures for the project. The project starts with literature review process where important informations regarding the project are searched. The information is then studied to understand all the related circuit especially that related to the regulator system

Then, simulation process is started. All of the circuits are simulated to ensure that the circuits are working. if there is any problems in the simulation, the circuits are rechecked and simulated back again.After the simulation process is successful, the prototypes of the circuits are built.

By completion of the circuit prototype, the process is then concentrated at the solar system. The solar system that consists of photovoltaic cells, solar battery and control circuit is constructed. Then, the output value for the solar system is tested with the simulation circuit.

After the output from the solar system is accepted, the solar system is then integrated with the previous circuit prototype. The result from the overall system is tested. When the result is justified, the prototype is accepted and the project is finished.

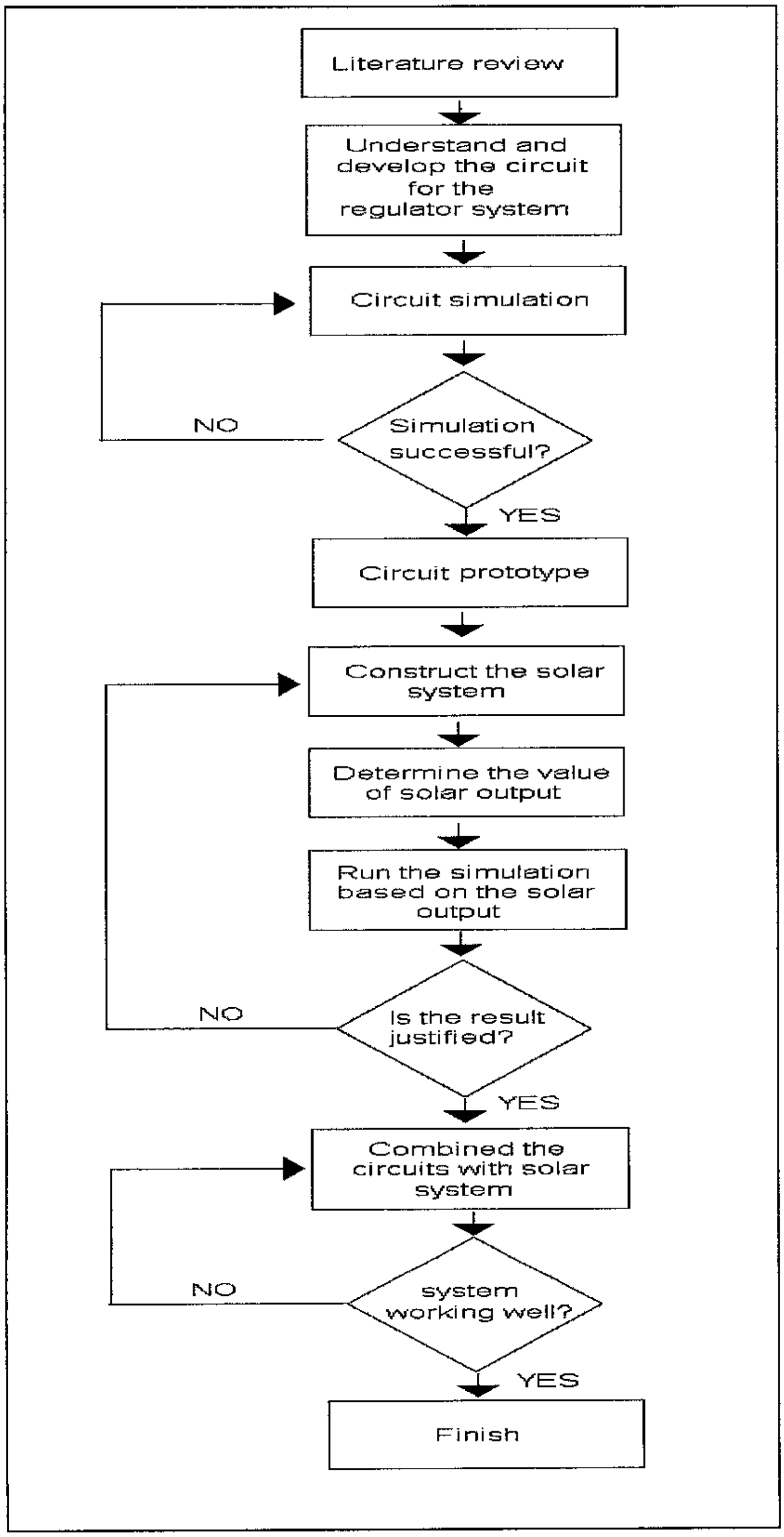


Figure 3.4: Flow Chart

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Rectifier, Filter and Regulator Circuit

Figure 4.1 shows the actual AC voltage produce at the transformer of the prototype. From the figure, the maximum positive voltage value is 17 VAC in a frequency of 50 Hz. Figure 4.2 shows the DC signal produce at the output of the regulator circuit. The maximum positive voltage value is 15.6 VDC with a peak to peak ripple voltage of 2.4 VDC.

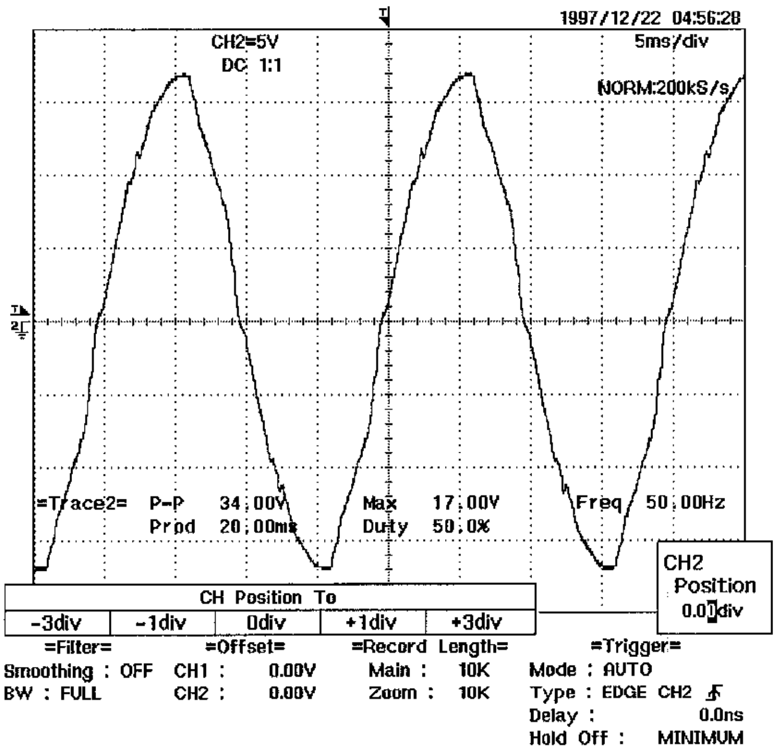


Figure 4.1: The Output of Transformer

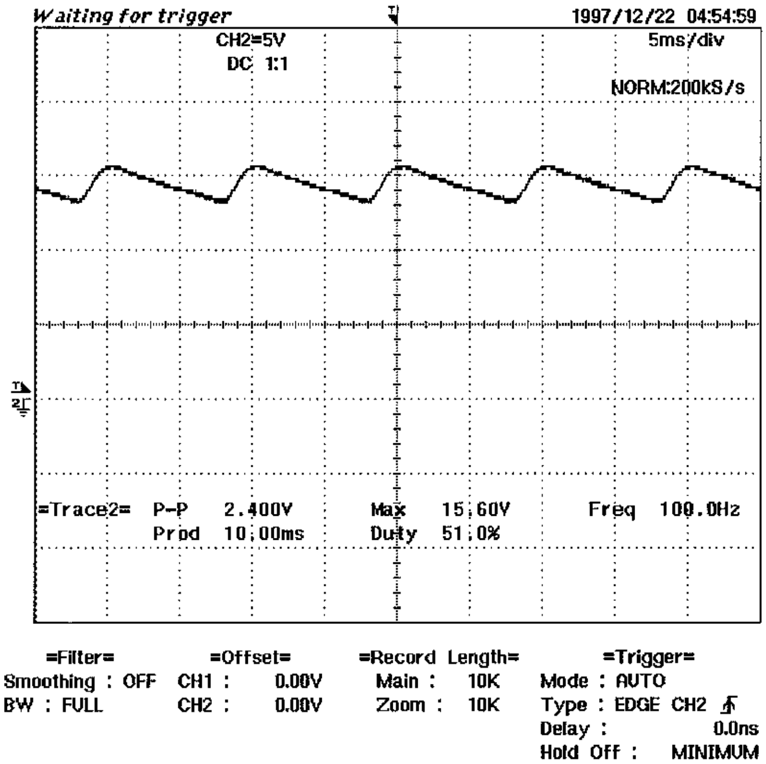


Figure 4.2: DC Voltage at Regulator Circuit Output

Figure 4.3 shows the picture of the simulation for rectifier, filter and regulator circuit simulation testing. From the simulation, using 240 VAC and 50 Hz the output DC voltage is 17.826 V.

4.1.2 Switching Circuit

Table 4.1 shows the result on the prototype switching circuit.

Table 4.1: Switching Circuit Prototype Results

Main Supply	Backup Energy	Output	Remarks
15.6 V	13.4 V	14.876 V	Voltage from main supply
15.6 V	0.0 V	14.876 V	Voltage from main supply
0.0 V	13.4 V	13.214 V	Voltage from backup energy

Figure 4.4, 4.5 and 4.6 shows the result of the simulation. Table 4.2 shows the result values for the simulation:

Table 4.2: Switching Circuit Simulation Results

Main Supply	Backup Energy	Output	Remarks
5.4 V	5.0 V	4.942 V	Voltage from main supply
5.4 V	0.0 V	4.942 V	Voltage from main supply
0.0 V	5.0 V	4.928 V	Voltage from backup energy

4.1.3 Photovoltaic Cell

The average voltage value produce by a single photovoltaic cell is around 7.4 VDC. From the prototype, the value produce is 14.0 VDC. Figure 4.7 shows the example of the value taken from the photovoltaic cell

4.1.4 240V Circuits

Figure 4.8, 4.9 and 4.10 show the result of the simulation. Table 4.3 shows the result values for the simulation:

Table 4.3: Simulation Result for 240 V

Main Supply	Backup Energy	Output	Remarks
240 V	240 V	239.898V	Voltage from main supply
240 V	0 V	239.898V	Voltage from main supply
0.0 V	240 V	208.179V	Voltage from backup energy

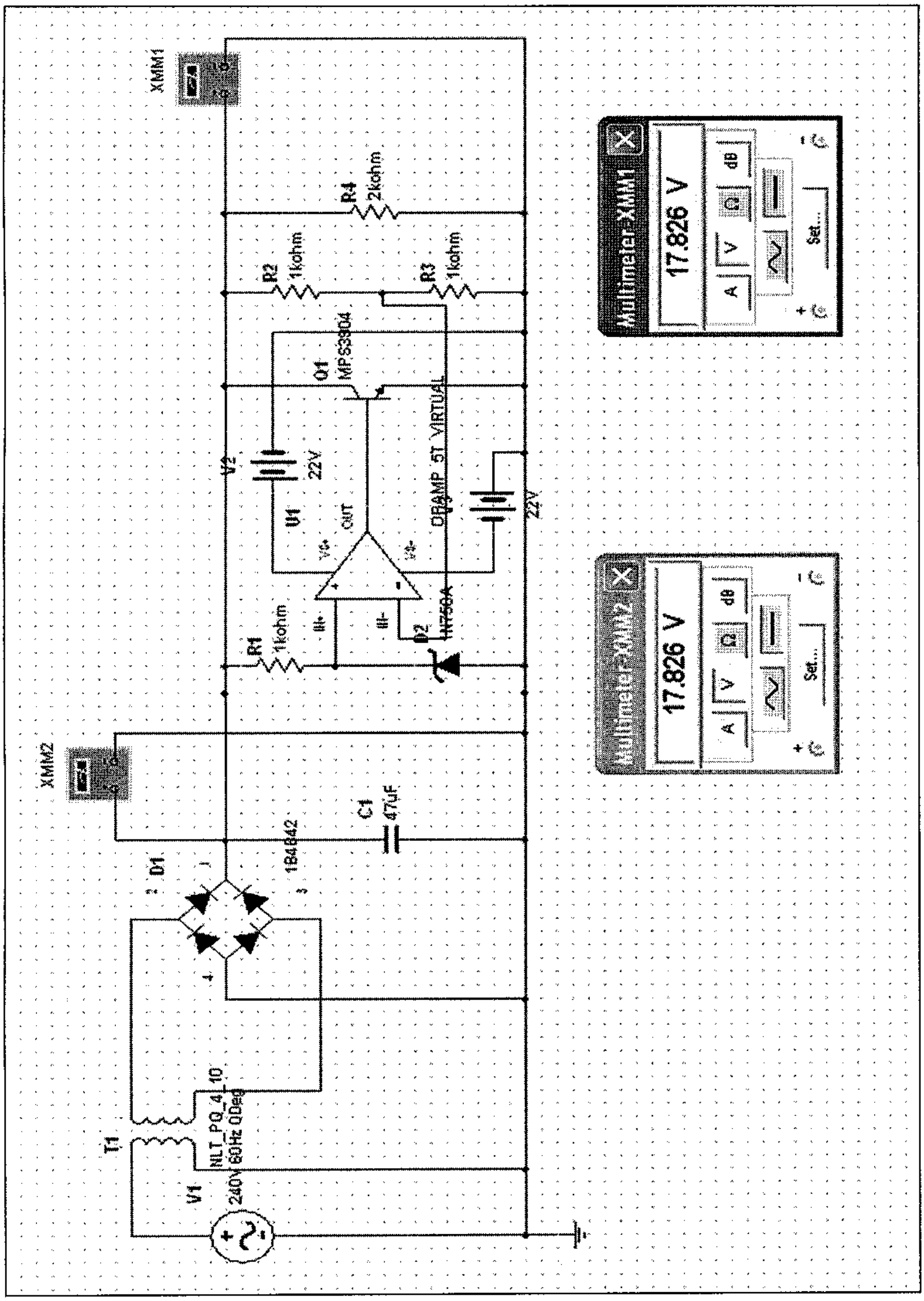


Figure 4.3: Rectifier, Filter and Regulator Circuit Simulation

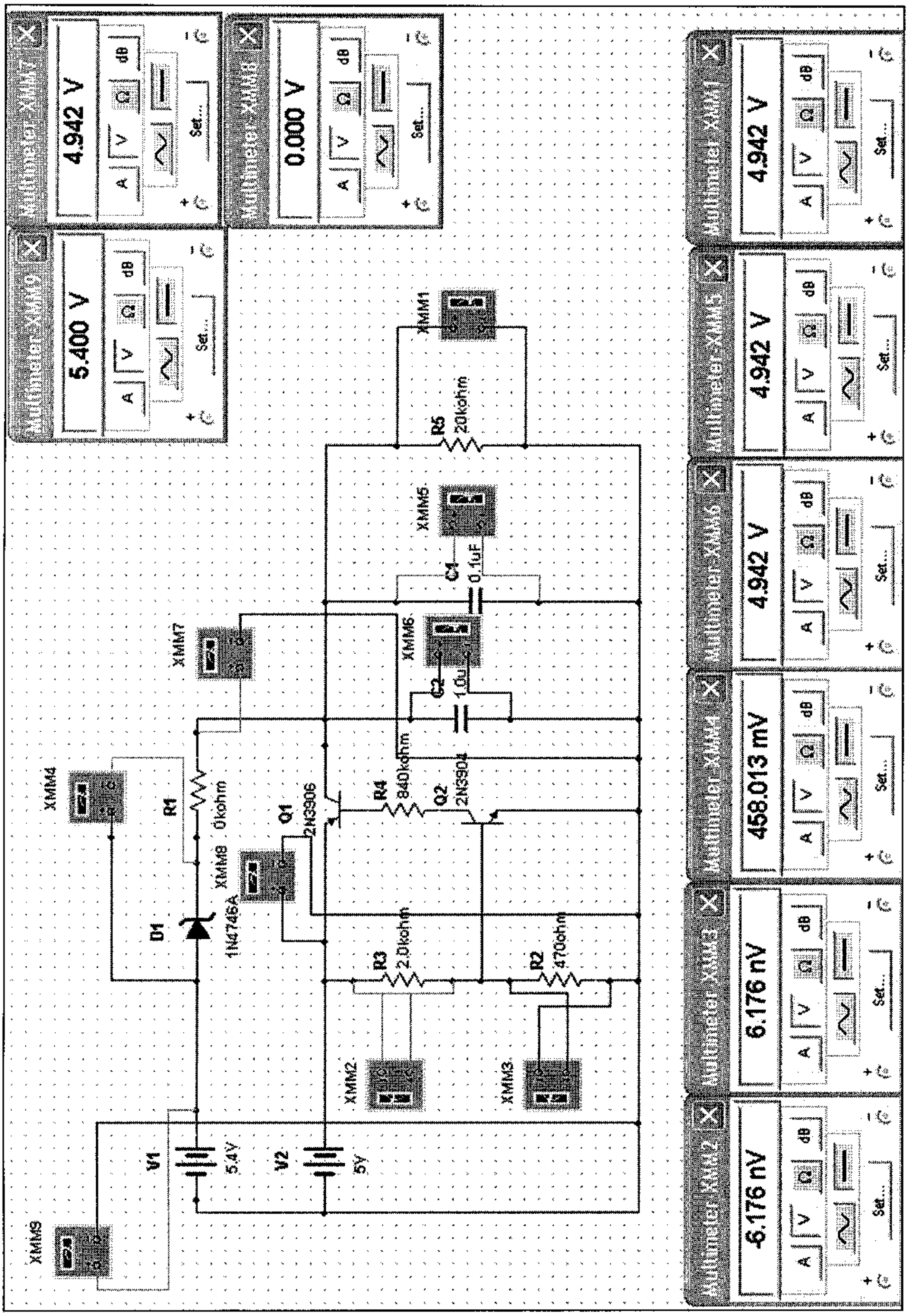


Figure 4.4: Switching Circuit (5.4V - 5.0V)

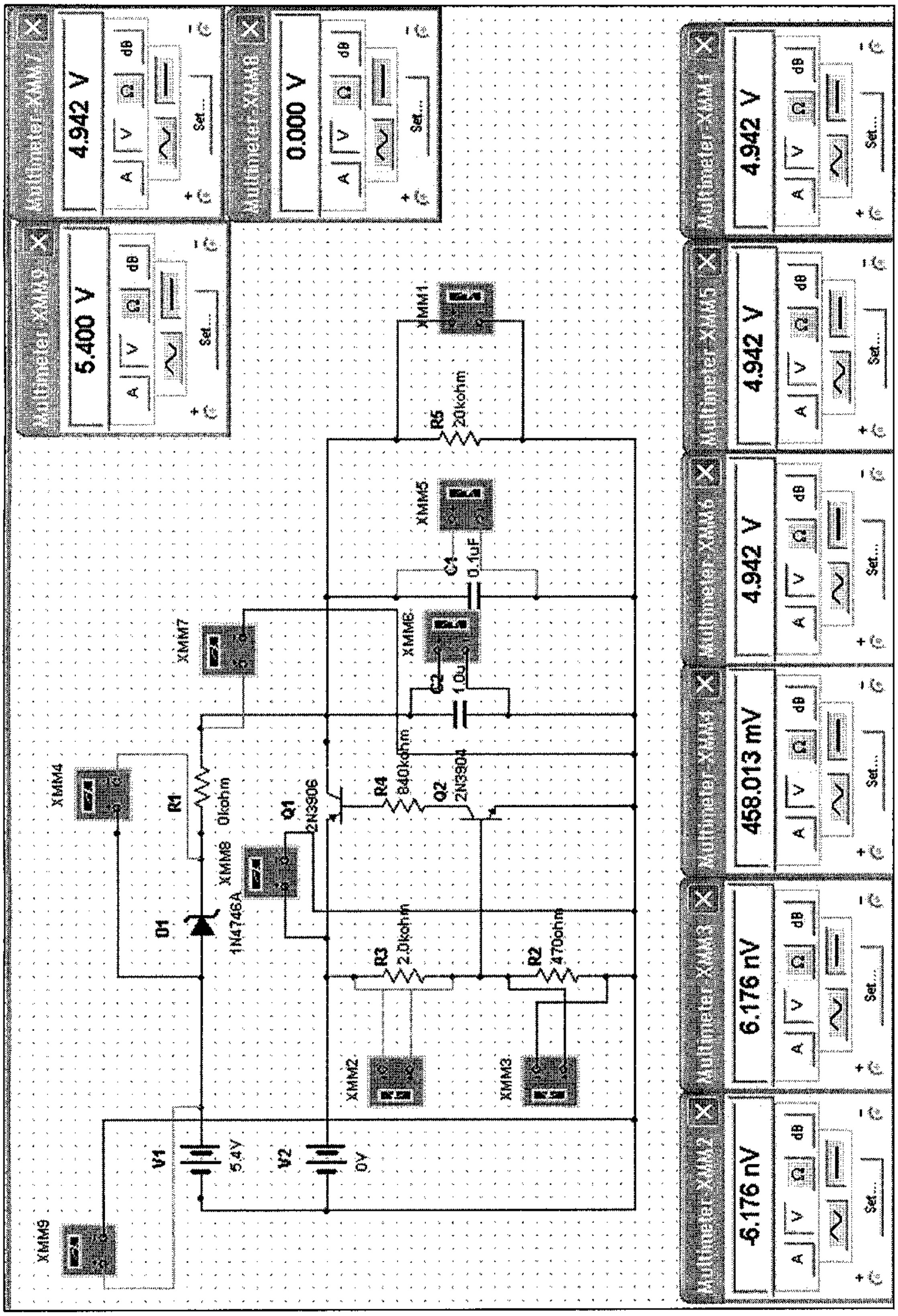


Figure 4.5: Switching Circuit (5.4V - 0.0V)

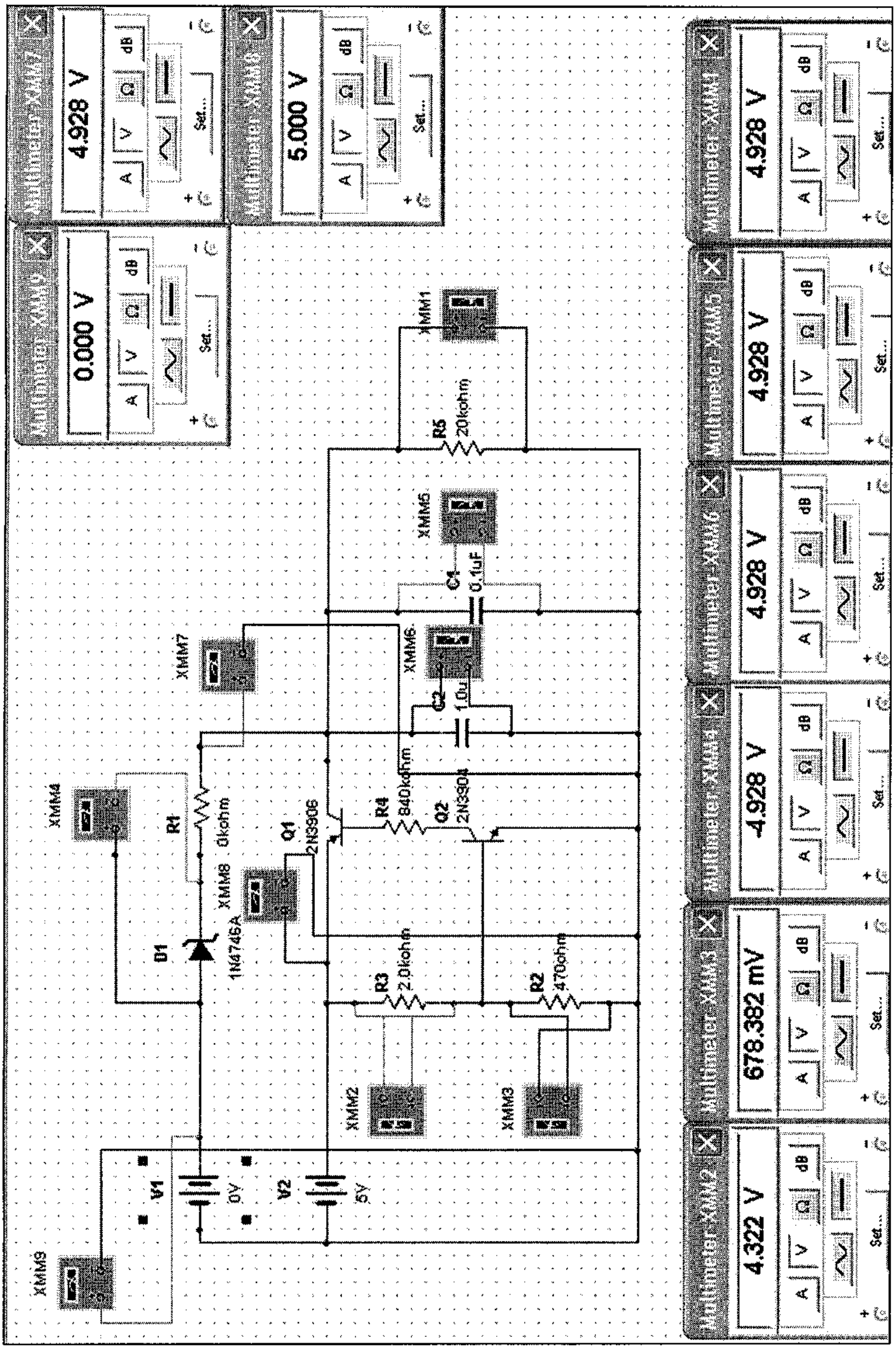


Figure 4.6: Switching Circuit (0.0V - 5.0V)

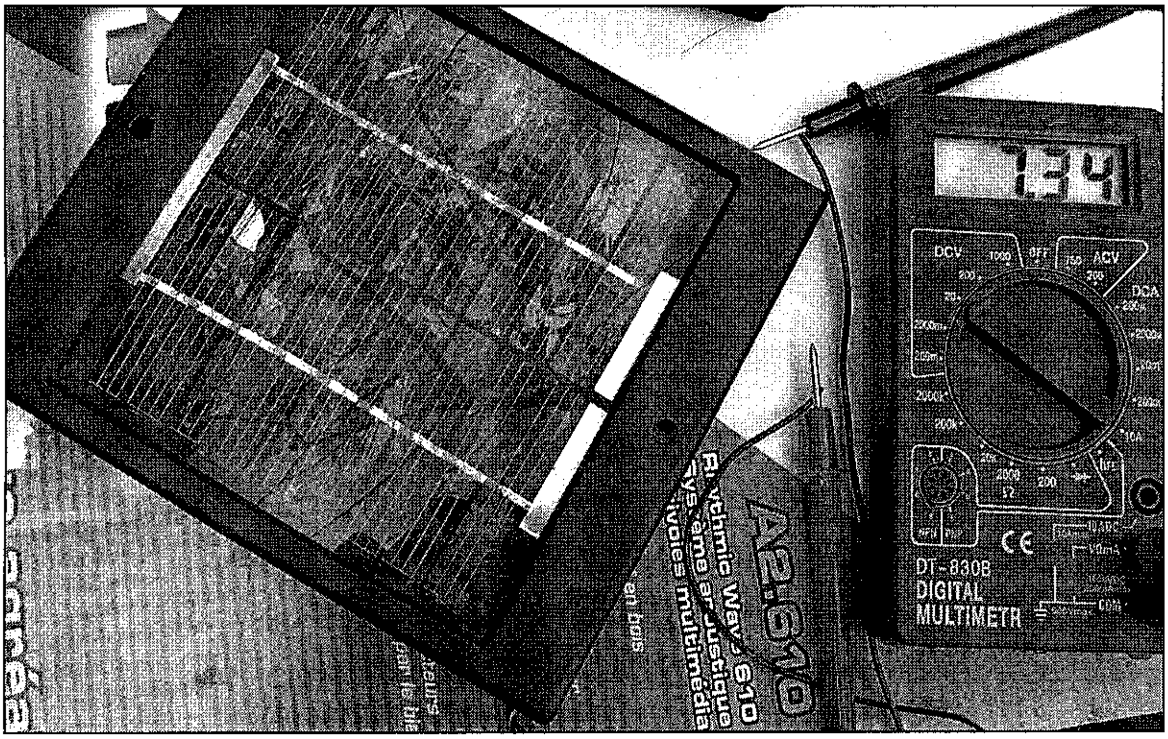


Figure 4.7: Photovoltaic Cell Sample Value

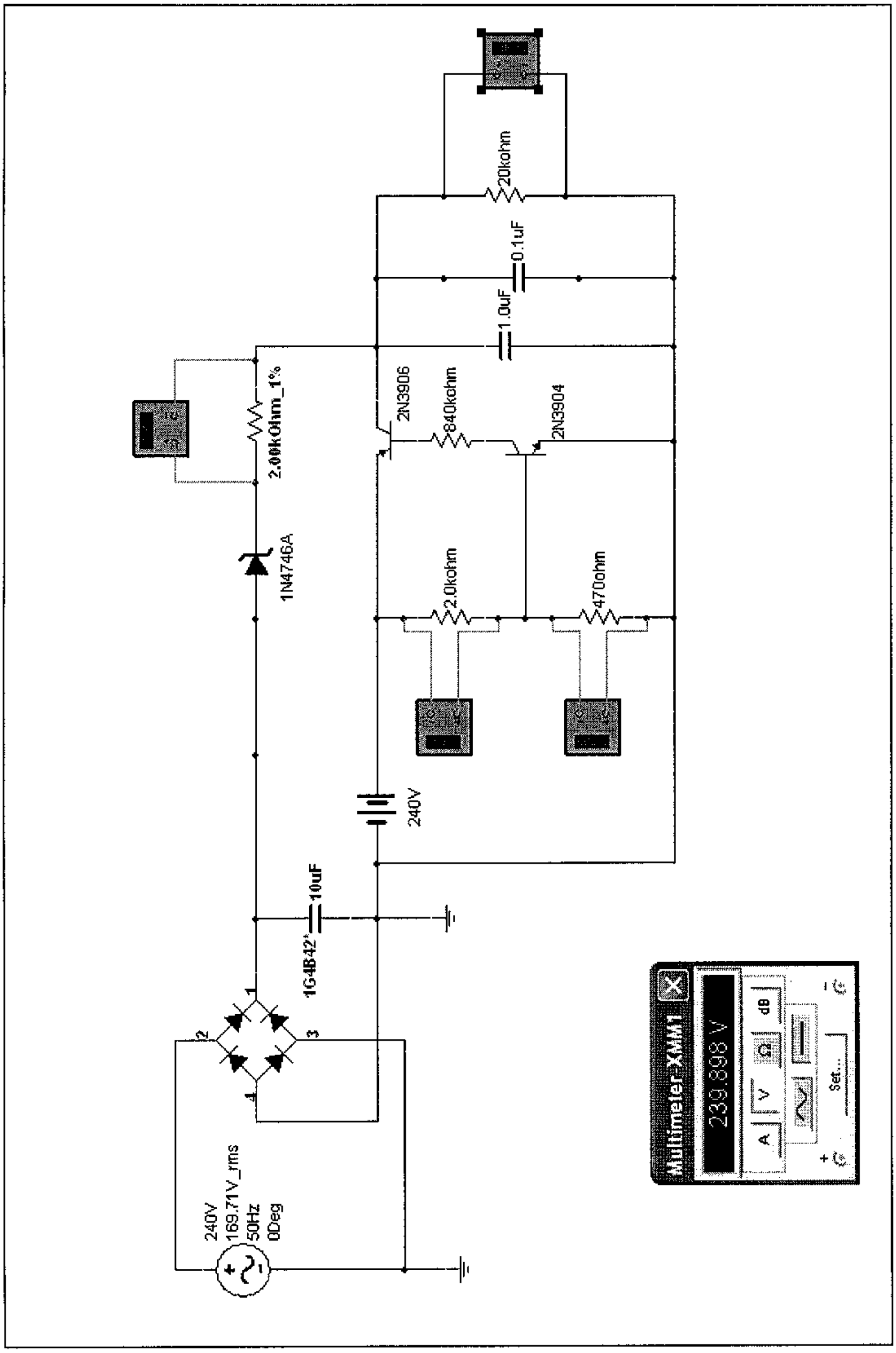


Figure 4.8: Switching Circuit (240V - 240V)

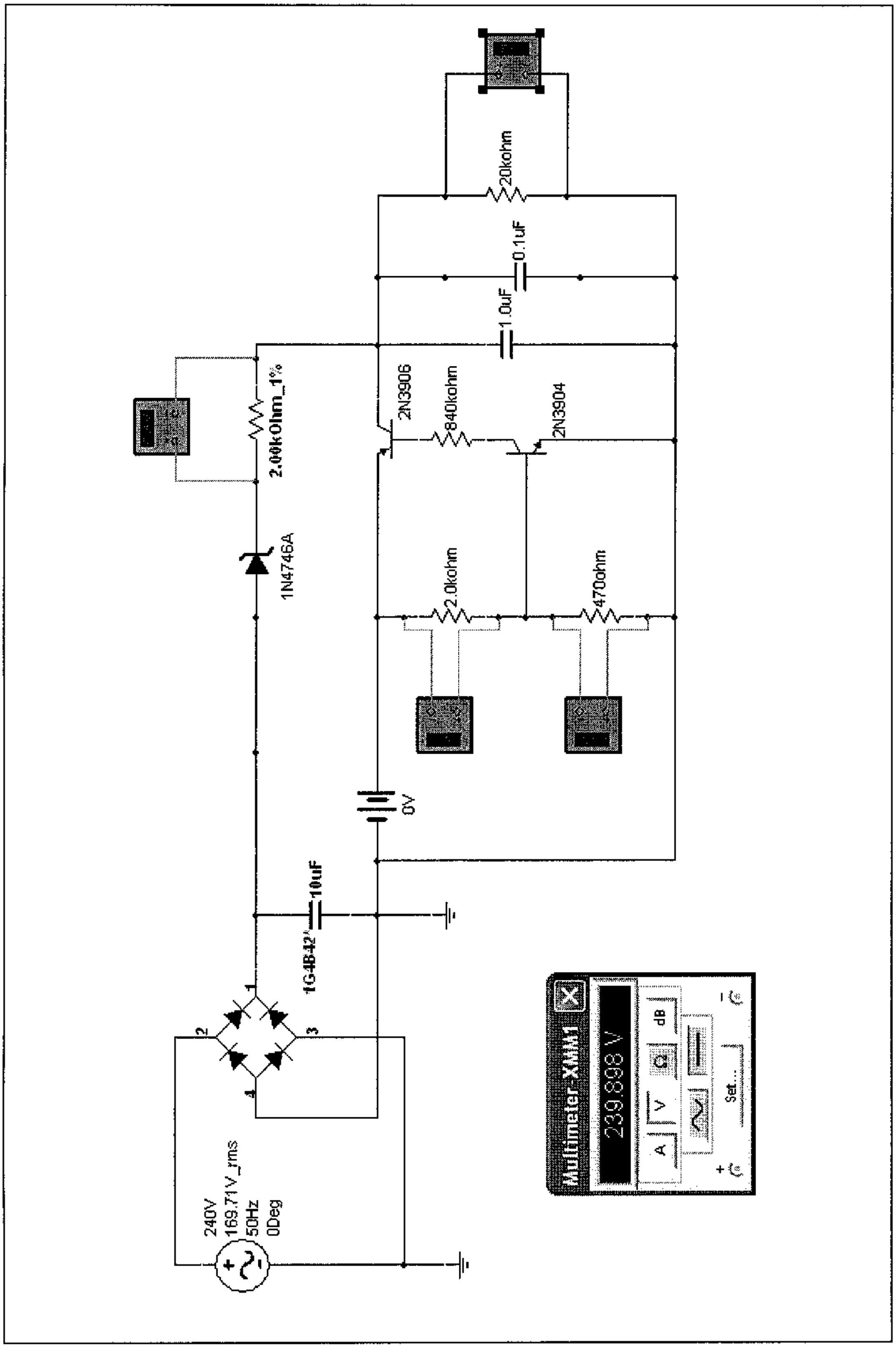


Figure 4.9: Switching Circuit (240V - 0V)

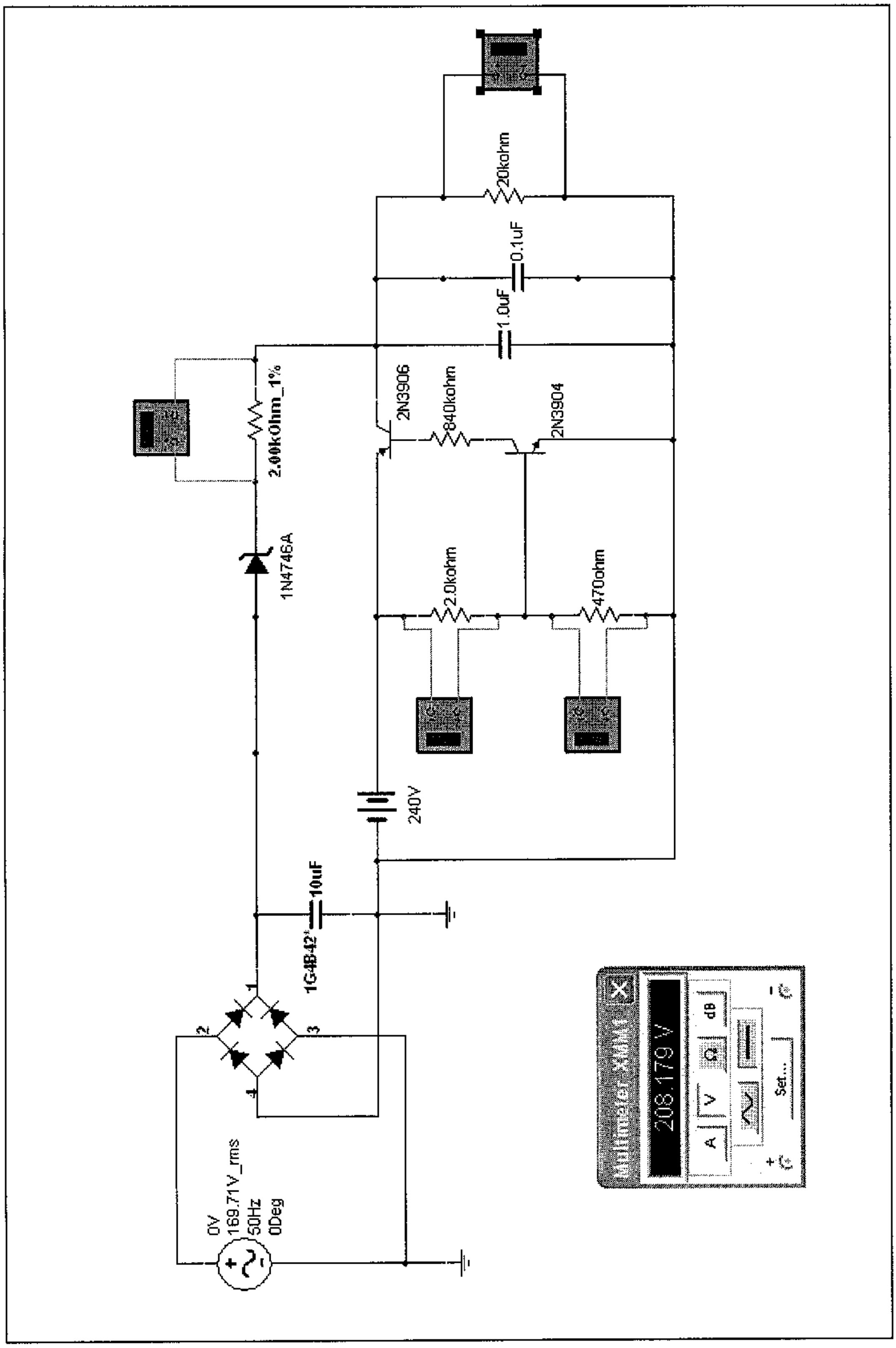


Figure 4.10: Switching Circuit (0V - 240V)

4.2 Discussion

4.2.1 Rectifier Circuit

This rectifier circuit uses four diodes - two are conducting at any one time. Note the configuration of the diodes. Diodes that are on parallel sides "point" in the same directions. The AC signal is fed to the points where a cathode and anode join. The positive output is taken from the junction of two cathodes. The other end of the load goes to the junction of two anodes [4]. Figure 4.9 shows the rectifier circuit together with the input and output signal.

The operation is simple, parallel-side diodes conduct at the same time. Note that the two + points are connected by a diode - same as in the two previous cases. The other end of the load returns to the transformer via the other parallel diode. When the polarity changes, the other two diodes conduct [4].

The main advantage of this rectifier circuit is that it is a simple rectifier circuit. It has no centre-tap and no extra winding. Diodes can be small and cheap. A bridge rectifier can also be purchased as a "block" with four wire connections.

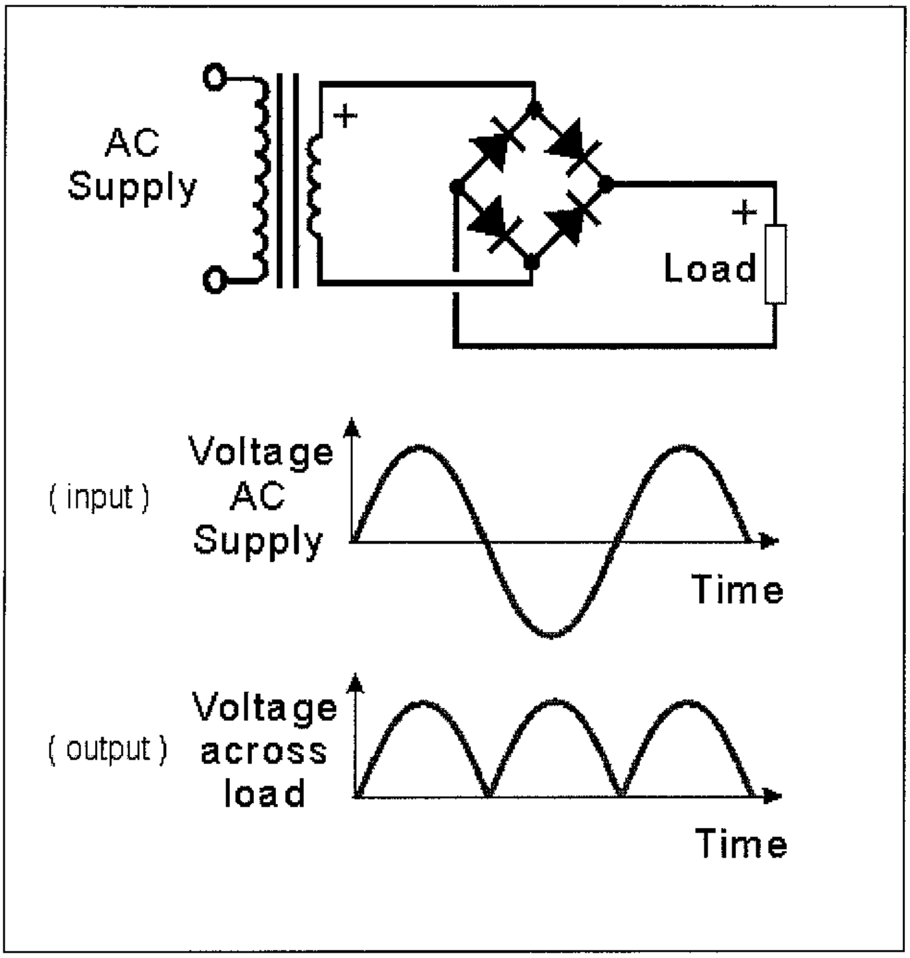


Figure 4.11: Rectifier Circuit Input and Output

4.2.2 Filter Circuit

Filter circuit basically is used to eliminate or accurately is to reduce ripple of a signal. When this filter is used, the RC charge time of the filter capacitor must be short and the RC discharge time must be long in order to eliminate ripple action. In other words, the capacitor must charge up fast, preferably with no discharge at all. Better filtering also results when the input frequency is high; therefore, the full-wave rectifier output is easier to filter than that of the half-wave rectifier because of its higher frequency [4]. Figure 4.12 shows the basic filter circuit together with the effect on reducing the ripple signal.

The application is that the capacitor wired across the load will charge up when the diode conducts and will discharge after the diode has stopped conducting. This reduces the size of the ripple. The blue lines in this diagram illustrate this.

The capacitor value chosen depends on the purpose for the supply. Capacities of the order of thousands of microfarads are common for low-voltage supplies. For supplies of 100V and upwards, the capacity is more likely to be 50 microfarad or so.

The rate of charge for the capacitor is limited only by the resistance of the conducting diode which is relatively low. Therefore, the RC charge time of the circuit is relatively short. As a result, when the pulsating voltage is first applied to the circuit, the capacitor charges rapidly and almost reaches the peak value of the rectified voltage within the first few cycles. The capacitor attempts to charge to the peak value of the rectified voltage anytime a diode is conducting, and tends to retain its charge when the rectifier output falls to zero. (The capacitor cannot discharge immediately.) The capacitor slowly discharges through the load resistance during the time the rectifier is nonconducting [4].

The rate of discharge of the capacitor is determined by the value of capacitance and the value of the load resistance. If the capacitance and load-resistance values are large, the RC discharge time for the circuit is relatively long.

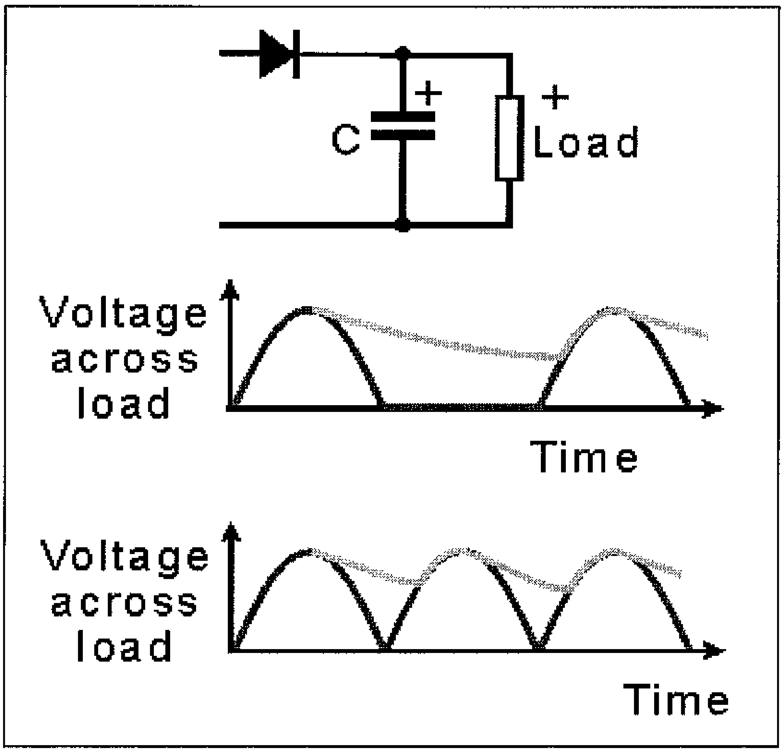


Figure 4.12: Filter Circuit and the Ripple Reduce Effect.

4.2.3 Regulator Circuit

A voltage regulator circuit provides a constant DC output voltage that is essentially independent of the input voltage, output load current and temperature. In other words, it can be said that it acts as a stabilizer for the output voltage. The control element is in series with the load between the input and output. The output sample circuit senses a change in the output voltage. The error detector compares the sample voltage with a reference voltage and causes the control element to compensate in order to maintain a constant output.

4.2.4 Switching Circuit

The switching circuit acts as a switch for a backup power supply. Once power breakdown occurs, the switching circuit will act to switch from the main supply to the solar energy (backup energy). In the simulation and prototype, both situation have been successfully tested and implemented in the project.

4.2.5 Simulation

From the rectifier, filter and regulator circuits result simulation, notice that the value of the output is 17.826 V. This value can be adjusted using voltage divider concept at the output. Others, the voltage can be said as stable, without any fluctuation at the output.

From the switching circuit results, notice that the output voltage value also can be categorize as stable. The only change in the load value is when the main supply is 0 V. The percentage of error is 0.283% ([4.942-4.938] / 4.942). This percentage of error is in the range on 5% and totally accepted.

During the simulation, there are also errors that have been considered such as rounding error and components error. This is because, during the simulation, the condition of each component is assumed in perfect condition without any tolerance. It is expected that the actual values will be slightly different from the values of the simulation.

For the circuit that can withstand 240 V, the simulation can be said as successful although the difference between output values is quite big. The difference at the output is 239.898 V – 208.179 V, which is 30.719 V.

4.2.6 Photovoltaic Cells

From the photovoltaic cell values, it can be seen that the value vary very much between each values. From the observation, the maximum value of the solar panel can reach up to 8.13V. The solar panel also is very sensitive to the weather. A glimpse of shadow can reduce the value around 0.1V - 0.4V.

4.2.7 Prototype

After several testing, the prototype of the project has been verified that it is working perfectly. Figure 4.13 shows the working model of the prototype. F or t esting purpose, a 12 VDC lamp has been used as the load. The switching time between main power supply and the solar energy can be ignored as it occurs spontaneously.

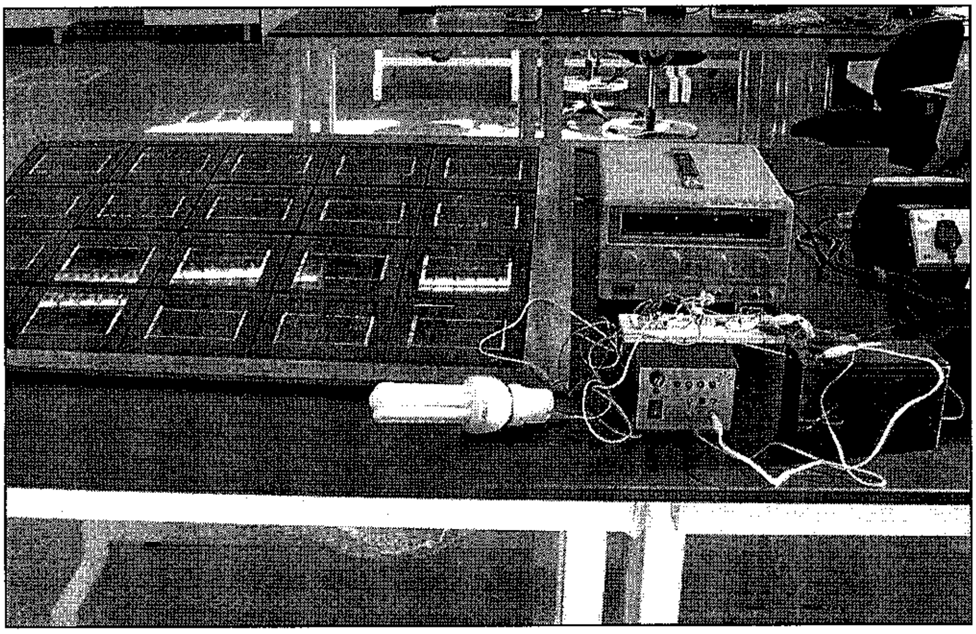


Figure 4.13: Prototype of the Project

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The preliminary aim of the project is achieved where a model of a system that can regulate the main power supply with solar energy was produced. All of the circuits that related for this project have been successfully simulated, tested and implemented.

The simulation for circuit that can withstand 240V supply also have been successfully done. It seems that the system actually can be implemented in a very cheap cost, but of course, many other constraints should be considered before it could be implemented such as the actual characteristic of the components, the tolerance and the budget for the system.

During the process of completing the project, many experience and knowledge have been gained by the author. Knowledge about the related circuits, operation of photovoltaic cell and solar batteries are some valuable knowledge learned. Besides, the used of Multisim2001 and Ultiboard software during the simulation and production of PCB board are also useful for the future. Experience of dealing with supervisor, suppliers, technicians and friends have helped a lot in improving the author's interpersonal and communication skills.

There are also problems in completing the project. Damaged equipment and electronic components are some of the problems during the project. Delays regarding the order of some part also have affected the overall schedule of the projects. But in the end, the project has been successfully completed in the given time.

5.2 Recommendation

As the first recommendation, the author would like to suggest that the prototype to be extended to withstand 240V and using highly efficient of solar panel if the budget for this project is raised. Same goes to other related component such as solar battery and solar control unit. This project would be very useful in power industry.

Besides, the project can also be altered using other renewable energy such as wind and wave energy. These energies would be very useful because of the reducing of oil, coal and other gas resources. In some research, forecast estimated that oil, coal and gas resource can only be used 60 years from now.

The author also recommended that the project can be varied using other regulating methods such as Programmable Logic Circuit (PLC) and Fuzzy Logic. By using other methods, the characteristic of the system regarding the power efficiency, related components and overall cost might be improved.

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7. <http://www.rain.org/~philfear/how2solar.html>
8. <http://my.integritynet.com.au/purdic/index.html#power-supply>

APPENDICES

APPENDIX A

(GANNT CHART)

Gantt Chart for Final Year Project
(for first semester)

No	Detail/Week	1	2	3	4	5	6	7	8 (Break)	9	10	11	12	13	14	15	16	17	18	19
1	Selection of topic																			
2	Literature Review																			
3	Configuration of Design Concept																			
4	Submission of Preliminary Research Work																			
5	Circuit Design																			
6	Submission of Progress Report																			
7	Circuit Design																			
8	Circuit Simulation, Testing and Analysis																			
9	Project Status Evaluation																			
10	Submission of Interim Report																			
11	Oral Presentation																			

Gantt Chart for Final Year Project
(for second semester)

No	Detail/Week	1	2	3	4	5	6	7 (Break)	8	9	10	11	12	13	14	15	16	17	18	19
1	Briefing by FYP committee																			
2	Laboratory Work																			
	- Complete the solar part																			
	- Chosse the suitable electronic devices																			
	- Construct the circuit																			
	- Testing the prototype																			
	- Fabricate the prototype																			
3	Desing for 240V circuit																			
4	Submission of Progress Report																			
5	Planning Documentation																			
6	Submission of Draft Report																			
7	Submission of Final Report (soft cover)																			
8	Revision on the current project status																			
9	Oral Presentation																			
10	Submission of Final Report (hard cover)	DUE ON FRIDAY (24TH DECEMBER 2004)																		

APPENDIX B

(1N746A DATASHEET)

FAIRCHILD
SEMICONDUCTOR®

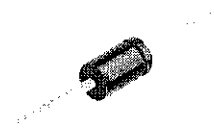
Zeners
1N4370A - 1N4372A
1N746A - 1N759A

Absolute Maximum Ratings * T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
P_D	Power Dissipation @ TL ■ 75°C, Lead Length = 3/8"	500	mW
	Derate above 75°C	4.0	mW/°C
T_J, T_{STG}	Operating and Storage Temperature Range	-65 to +200	°C

* These ratings are limiting values above which the serviceability of the diode may be impaired.

Tolerance = 5%



DO-35 Glass case
COLOR BAND DENOTES CATHODE

Electrical Characteristics T_A=25°C unless otherwise noted

Device	V_Z (V) @ I_Z = 20mA (Note 1)			Z_Z (■) @ I_Z = 20mA	I_{ZM} (mA) (Note 2)	I_R (■A) @ V_R = 1V	
	Min.	Typ.	Max.			Ta = 25°C	Ta = 125°C
1N4370A	2.28	2.4	2.52	30	150	100	200
1N4371A	2.57	2.7	2.84	30	135	75	150
1N4372A	2.85	3.0	3.15	29	120	50	100
1N746A	3.14	3.3	3.47	28	110	10	30
1N747A	3.42	3.6	3.78	24	100	10	30
1N748A	3.71	3.9	4.10	23	95	10	30
1N749A	4.09	4.3	4.52	22	85	2	30
1N750A	4.47	4.7	4.94	19	75	2	30
1N751A	4.85	5.1	5.36	17	70	1	20
1N752A	5.32	5.6	5.88	11	65	1	20
1N753A	5.89	6.2	6.51	7	60	0.1	20
1N754A	6.46	6.8	7.14	5	55	0.1	20
1N755A	7.13	7.5	7.88	6	50	0.1	20
1N756A	7.79	8.2	8.61	8	45	0.1	20
1N757A	8.65	9.1	9.56	10	40	0.1	20
1N758A	9.50	10	10.5	17	35	0.1	20
1N759A	11.40	12	12.6	30	30	0.1	20

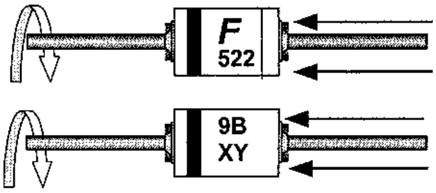
V_F Forward Voltage = 1.5V Max @ I_F = 200mA

Notes:
1. Zener Voltage (V_Z)
The zener voltage is measured with the device junction in the thermal equilibrium at the lead temperature (T_L) at 30°C ± 1°C and 3/8" lead length.
2. Maximum Zener Current Ratings (I_{ZM})
The maximum current handling capability on a worst case basis is limited by the actual zener voltage at the operation point and the power derating curve.

Top Mark Information

Device	Line 1	Line 2	Line 3	Line 5
1N4370A	LOGO	437	0A	XY
1N4371A	LOGO	437	1A	XY
1N4372A	LOGO	437	2A	XY
1N746A	LOGO	746	A	XY
1N747A	LOGO	747	A	XY
1N748A	LOGO	748	A	XY
1N749A	LOGO	749	A	XY
1N750A	LOGO	750	A	XY
1N751A	LOGO	751	A	XY
1N752A	LOGO	752	A	XY
1N753A	LOGO	753	A	XY
1N754A	LOGO	754	A	XY
1N755A	LOGO	755	A	XY
1N756A	LOGO	756	A	XY
1N757A	LOGO	757	A	XY
1N758A	LOGO	758	A	XY
1N759A	LOGO	759	A	XY

Top Mark Information (Continued)



1st line: F - Fairchild Logo

2nd line: Device Name - 3rd to 5th characters of the device name.
or 4th to 6th characters for BZXyy series

3rd line: Device Name - 6th to 7th characters of the device name.
or Voltage rating for BZXyy series

4th line: Device Code or - Two Digit - Six Weeks Date Code.
Date code plus or Two Digit - Six Weeks Date Code
Large die identification plus Large die identification, "L"

General Requirements:

1.0 Cathod Band

2.0 First Line: F - Fairchild Logo

3.0 Second Line: Device name - For 1Nxx series: 3rd to 5th characters of the device name.
For BZxx series: 4th to 6th characters of the device name.

4.0 Third Line: Device name - For 1Nxx series: 6th to 7th characters of the device name.
For BZXyy series: Voltage rating

5.0 Fourth Line: XY or XYL - Two Digit - Six Weeks Date Code
Where: X represents the last digit of the calendar year
Y represents the Six weeks numeric code
L represents the Large die identification

6.0 Devices shall be marked as required in the device specification (PID or FSC Test Spec).

7.0 Maximum no. of marking lines: 4

8.0 Maximum no. of digits per line: 3

9.0 FSC logo must be 20 % taller than the alphanumeric marking and should occupy the 2 characters of the specified line.

10.0 Marking Font: Arial (Except FSC Logo)

11.0 First character of each marking line must be aligned vertically

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Bottomless™	FASTr™	LittleFET™	Power247™	SuperFET™
CoolFET™	FPS™	MICROCOUPLER™	PowerSaver™	SuperSOT™-3
CROSSVOLT™	FRFET™	MicroFET™	PowerTrench®	SuperSOT™-6
DOME™	GlobalOptoisolator™	MicroPak™	QFET®	SuperSOT™-8
EcoSPARK™	GTO™	MICROWIRE™	QS™	SyncFET™
E^{2}CMOS™	HiSeC™	MSX™	QT Optoelectronics™	TinyLogic®
EnSigna™	I^{2}C™	MSXPro™	Quiet Series™	TINYOPTO™
FACT™	*i-Lo*™	OCX™	RapidConfigure™	TruTranslation™
Across the board. Around the world.™		OCXPro™	RapidConnect™	UHC™
The Power Franchise®		OPTOLOGIC®	SILENT SWITCHER®	UltraFET®
Programmable Active Droop™		OPTOPLANAR™	SMART START™	VCX™

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

PRODUCT STATUS DEFINITIONS

Definition of Terms

Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

Rev. I10

APPENDIX C

(1N4764A DATASHEET)

FAIRCHILD
SEMICONDUCTOR®

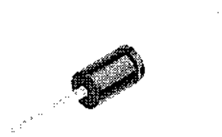
Zeners
1N4728A - 1N4764A

Absolute Maximum Ratings * T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
P_D	Power Dissipation @ TL ■ 50°C, Lead Length = 3/8"	1.0	W
	Derate above 50°C	6.67	mW/°C
T_J, T_{STG}	Operating and Storage Temperature Range	-65 to +200	°C

* These ratings are limiting values above which the serviceability of the diode may be impaired.

Tolerance = 5%



DO-41 Glass case
COLOR BAND DENOTES CATHODE

Electrical Characteristics T_A=25°C unless otherwise noted

Device	V_Z (V) @ I_Z (Note 1)			Test Current	Max. Zener Impedance			Leakage Current	
	Min.	Typ.	Max.	I_Z (mA)	Z_Z @ I_Z (■)	Z_{ZK} @ I_{ZK} (■)	I_{ZK} (mA)	I_R (■A)	V_R (V)
1N4728A	3.315	3.3	3.465	76	10	400	1	100	1
1N4729A	3.42	3.6	3.78	69	10	400	1	100	1
1N4730A	3.705	3.9	4.095	64	9	400	1	50	1
1N4731A	4.085	4.3	4.515	58	9	400	1	10	1
1N4732A	4.465	4.7	4.935	53	8	500	1	10	1
1N4733A	4.845	5.1	5.355	49	7	550	1	10	1
1N4734A	5.32	5.6	5.88	45	5	600	1	10	2
1N4735A	5.89	6.2	6.51	41	2	700	1	10	3
1N4736A	6.46	6.8	7.14	37	3.5	700	1	10	4
1N4737A	7.125	7.5	7.875	34	4	700	0.5	10	5
1N4738A	7.79	8.2	8.61	31	4.5	700	0.5	10	6
1N4739A	8.645	9.1	9.555	28	5	700	0.5	10	7
1N4740A	9.5	10	10.5	25	7	700	0.25	10	7.6
1N4741A	10.45	11	11.55	23	8	700	0.25	5	8.4
1N4742A	11.4	12	12.6	21	9	700	0.25	5	9.1
1N4743A	12.35	13	13.65	19	10	700	0.25	5	9.9
1N4744A	14.25	15	15.75	17	14	700	0.25	5	11.4
1N4745A	15.2	16	16.8	15.5	16	700	0.25	5	12.2
1N4746A	17.1	18	18.9	14	20	700	0.25	5	13.7
1N4747A	19	20	21	12.5	22	700	0.25	5	15.2
1N4748A	20.9	22	23.1	11.5	23	750	0.25	5	16.7
1N4749A	22.8	24	25.2	10.5	25	750	0.25	5	18.2
1N4750A	25.65	27	28.35	9.5	35	750	0.25	5	20.6
1N4751A	28.5	30	31.5	8.5	40	1000	0.25	5	22.8
1N4752A	31.35	33	34.65	7.5	45	1000	0.25	5	25.1
1N4753A	34.2	36	37.8	7	50	1000	0.25	5	27.4
1N4754A	37.05	39	40.95	6.5	60	1000	0.25	5	29.7
1N4755A	40.85	43	45.15	6	70	1500	0.25	5	32.7
1N4756A	44.65	47	49.35	5.5	80	1500	0.25	5	35.8
1N4757A	48.45	51	53.55	5	95	1500	0.25	5	38.8

Electrical Characteristics (Continued) T_A=25°C unless otherwise noted

Device	V_Z (V) @ I_Z (Note 1)			Test Current I_Z (mA)	Max. Zener Impedance			Leakage Current	
	Min.	Typ.	Max.		Z_Z @ I_Z (■)	Z_{ZK} @ I_{ZK} (■)	I_{ZK} (mA)	I_R (■A)	V_R (V)
1N4758A	53.2	56	58.8	4.5	110	2000	0.25	5	42.6
1N4759A	58.9	62	65.1	4	125	2000	0.25	5	47.1
1N4760A	64.6	68	71.4	3.7	150	2000	0.25	5	51.7
1N4761A	71.25	75	78.75	3.3	175	2000	0.25	5	56
1N4762A	77.9	82	86.1	3	200	3000	0.25	5	62.2
1N4763A	86.45	91	95.55	2.8	250	3000	0.25	5	69.2
1N4764A	95	100	105	2.5	350	3000	0.25	5	76

V_F Forward Voltage = 1.2V Max @ I_F = 200mA

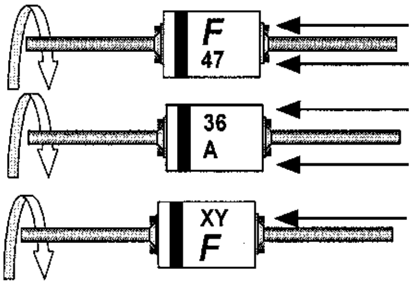
Notes:

1. Zener Voltage (V_Z)
   The zener voltage is measured with the device junction in the thermal equilibrium at the lead temperature (T_L) at 30°C ± 1°C and 3/8" lead length.

Top Mark Information

Device	Line 1	Line 2	Line 3	Line 4	Line 5
1N4728A	LOGO	47	28	A	XY
1N4729A	LOGO	47	29	A	XY
1N4730A	LOGO	47	30	A	XY
1N4731A	LOGO	47	31	A	XY
1N4732A	LOGO	47	32	A	XY
1N4733A	LOGO	47	33	A	XY
1N4734A	LOGO	47	34	A	XY
1N4735A	LOGO	47	35	A	XY
1N4736A	LOGO	47	36	A	XY
1N4737A	LOGO	47	37	A	XY
1N4738A	LOGO	47	38	A	XY
1N4739A	LOGO	47	39	A	XY
1N4740A	LOGO	47	40	A	XY
1N4741A	LOGO	47	41	A	XY
1N4742A	LOGO	47	42	A	XY
1N4743A	LOGO	47	43	A	XY
1N4744A	LOGO	47	44	A	XY
1N4745A	LOGO	47	45	A	XY
1N4746A	LOGO	47	46	A	XY
1N4747A	LOGO	47	47	A	XY
1N4748A	LOGO	47	48	A	XY
1N4749A	LOGO	47	49	A	XY
1N4750A	LOGO	47	50	A	XY
1N4751A	LOGO	47	51	A	XY
1N4752A	LOGO	47	52	A	XY
1N4753A	LOGO	47	53	A	XY
1N4754A	LOGO	47	54	A	XY
1N4755A	LOGO	47	55	A	XY
1N4756A	LOGO	47	56	A	XY
1N4757A	LOGO	47	57	A	XY
1N4758A	LOGO	47	58	A	XY
1N4759A	LOGO	47	59	A	XY
1N4760A	LOGO	47	60	A	XY
1N4761A	LOGO	47	61	A	XY
1N4762A	LOGO	47	62	A	XY
1N4763A	LOGO	47	63	A	XY
1N4764A	LOGO	47	64	A	XY

Top Mark Information (Continued)



1^{st} line: F - Fairchild Logo

2^{nd} line: Device Name - 3^{rd} to 4^{th} characters of device name for 1Nxx series or 4^{th} to 6^{th} characters for BZXyy series

3^{rd} line: Device Name - 5^{th} to 6^{th} characters of device name for 1Nxx series or Voltage rating for BZXyy series

4^{th} line: Device Name - 7^{th} to 8^{th} characters of device name for 1Nxx series or Large Die identification only for BZXyy series

5^{th} line: Date Code - Two Digit - Six Weeks Date Code

General Requirements:

1.0 Cathod Band

2.0 First Line: F - Fairchild Logo

3.0 Second Line: Device name - For 1Nxx series: 3^{rd} to 4^{th} characters of the device name.
For BZxx series: 4^{th} to 6^{th} characters of the device name.

4.0 Third Line: Device name - For 1Nxx series: 5^{th} to 6^{th} characters of the device name.
For BZXyy series: Voltage rating

5.0 Third Line: Device name - For 1Nxx series: 7^{th} to 8^{th} characters of the device name.
(the 8th character is the large die identification)
For BZXyy series: Large Die Identification character

6.0 Fourth Line: Date Code - Two Digit - Six Weeks Date Code
Where: X represents the last digit of the calendar year
Y represents the Six weeks numeric code

7.0 Devices shall be marked as required in the device specification (PID or FSC Test Spec).

8.0 Maximum no. of marking lines: 5

9.0 Maximum no. of digits per line: 3

10.0 FSC logo must be 20 % taller than the alphanumeric marking and should occupy the 2 characters of the specified line.

11.0 Marking Font: Arial (Except FSC Logo)

12.0 First character of each marking line must be aligned vertically

TRADEMARKS

The following are registered and unregistered trademarks Fairchild Semiconductor owns or is authorized to use and is not intended to be an exhaustive list of all such trademarks.

ACEx™	FACT Quiet Series™	ImpliedDisconnect™	PACMAN™	SPM™
ActiveArray™	FAST®	ISOPLANAR™	POP™	Stealth™
Bottomless™	FASTr™	LittleFET™	Power247™	SuperFET™
CoolFET™	FPS™	MICROCOUPLER™	PowerSaver™	SuperSOT™-3
CROSSVOLT™	FRFET™	MicroFET™	PowerTrench®	SuperSOT™-6
DOME™	GlobalOptoisolator™	MicroPak™	QFET®	SuperSOT™-8
EcoSPARK™	GTO™	MICROWIRE™	QS™	SyncFET™
E^2CMOS™	HiSeC™	MSX™	QT Optoelectronics™	TinyLogic®
EnSigna™	I^2C™	MSXPro™	Quiet Series™	TINYOPTO™
FACT™	*i-Lo*™	OCX™	RapidConfigure™	TruTranslation™
Across the board. Around the world.™		OCXPro™	RapidConnect™	UHC™
The Power Franchise®		OPTOLOGIC®	SILENT SWITCHER®	UltraFET®
Programmable Active Droop™		OPTOPLANAR™	SMART START™	VCX™

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FAIRCHILD'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF FAIRCHILD SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, or (c) whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in significant injury to the user.

2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

PRODUCT STATUS DEFINITIONS

Definition of Terms

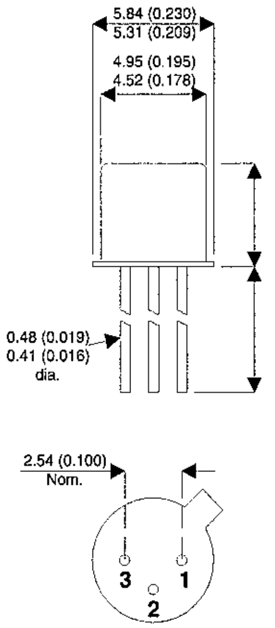
Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

APPENDIX D

(2N2906 DATASHEET)

2N2906

nensions in mm (inches).



TO18 (TO206AA)
PINOUTS

1 – Emitter 2 – Base 3 – Collector

Bipolar PNP Device in a Hermetically sealed TO18 Metal Package.

Bipolar PNP Device.

V_{CEO} = 40V

I_C = 0.6A

All Semelab hermetically sealed products can be processed in accordance with the requirements of BS, CECC and JAN, JANTX, JANTXV and JANS specifications

ırameter	Test Conditions	Min.	Typ.	Max.	Units
EO *				40	V
:ONT)				0.6	A
:	@ 10/0.15 (V_{CE} / I_C)	40		120	-
			200M		Hz
				0.4	W

/laximum Working Voltage

ıis is a shortform datasheet. For a full datasheet please contact sales@semelab.co.uk.

ıelab plc. Telephone +44(0)1455 556565. Fax +44(0)1455 552612.

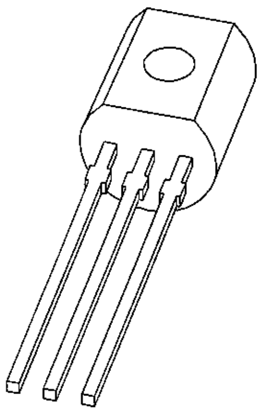
E-mail: sales@semelab.co.uk Website: http://www.semelab.co.uk

Generated
2-Aug-02

APPENDIX E

(2N3904 DATASHEET)

DATA SHEET



2N3904
NPN switching transistor

Product specification
Supersedes data of September 1994
File under Discrete Semiconductors, SC04

1997 Jul 15

Philips
Semiconductors

PHILIPS

NPN switching transistor 2N3904

FEATURES

- Low current (max. 200 mA)
- Low voltage (max. 40 V).

APPLICATIONS

- High-speed switching.

DESCRIPTION

NPN switching transistor in a TO-92; SOT54 plastic package. PNP complement: 2N3906.

PINNING

PIN	DESCRIPTION
1	collector
2	base
3	emitter

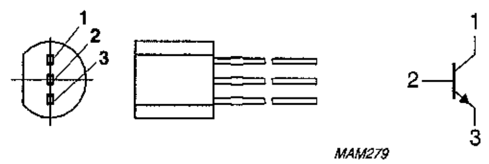


Fig.1 Simplified outline (TO-92; SOT54) and symbol.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter	–	60	V
V_{CEO}	collector-emitter voltage	open base	–	40	V
I_C	collector current (DC)		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	500	mW
h_{FE}	DC current gain	$I_C = 10$ mA; $V_{CE} = 1$ V	100	300	
f_T	transition frequency	$I_C = 10$ mA; $V_{CE} = 20$ V; f = 100 MHz	300	–	MHz
t_{off}	turn-off time	$I_{Con} = 10$ mA; $I_{Bon} = 1$ mA; $I_{Boff} = -1$ mA	–	240	ns

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter	–	60	V
V_{CEO}	collector-emitter voltage	open base	–	40	V
V_{EBO}	emitter-base voltage	open collector	–	6	V
I_C	collector current (DC)		–	200	mA
I_{CM}	peak collector current		–	300	mA
I_{BM}	peak base current		–	100	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C; note 1	–	500	mW
T_{stg}	storage temperature		–65	+150	°C
T_j	junction temperature		–	150	°C
T_{amb}	operating ambient temperature		–65	+150	°C

Note

1. Transistor mounted on an FR4 printed-circuit board.

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	note 1	250	K/W

Note

1. Transistor mounted on an FR4 printed-circuit board.

CHARACTERISTICS

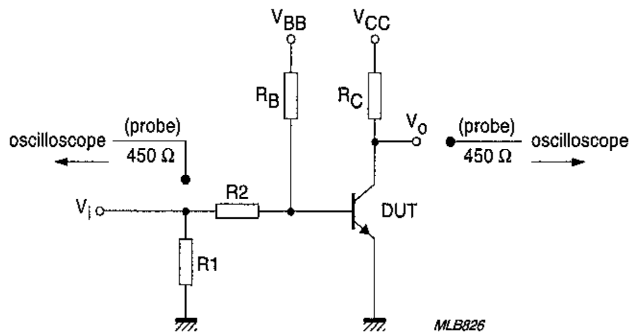
$T_{amb} = 25$ °C.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
I_{CBO}	collector cut-off current	$I_E = 0$; $V_{CB} = 30$ V	–	50	nA
I_{EBO}	emitter cut-off current	$I_C = 0$; $V_{EB} = 6$ V	–	50	nA
h_{FE}	DC current gain	$V_{CE} = 1$ V; note 1			
		$I_C = 0.1$ mA	60	–	
		$I_C = 1$ mA	80	–	
		$I_C = 10$ mA	100	300	
		$I_C = 50$ mA	60	–	
		$I_C = 100$ mA	30	–	
V_{CEsat}	collector-emitter saturation voltage	$I_C = 10$ mA; $I_B = 1$ mA; note 1	–	200	mV
		$I_C = 50$ mA; $I_B = 5$ mA; note 1	–	200	mV
V_{BEsat}	base-emitter saturation voltage	$I_C = 10$ mA; $I_B = 1$ mA; note 1	–	850	mV
		$I_C = 50$ mA; $I_B = 5$ mA; note 1	–	950	mV
C_c	collector capacitance	$I_E = i_e = 0$; $V_{CB} = 5$ V; f = 1 MHz	–	4	pF
C_e	emitter capacitance	$I_C = i_c = 0$; $V_{EB} = 500$ mV; f = 1 MHz	–	8	pF
f_T	transition frequency	$I_C = 10$ mA; $V_{CE} = 20$ V; f = 100 MHz	300	–	MHz

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
F	noise figure	I_C = 100 μA; V_{CE} = 5 V; R_S = 1 kΩ; f = 10 Hz to 15.7 kHz	–	5	dB
Switching times (between 10% and 90% levels); see Fig.2					
t_{on}	turn-on time	I_{Con} = 10 mA; I_{Bon} = 1 mA; I_{Boff} = −1 mA	–	65	ns
t_d	delay time		–	35	ns
t_r	rise time		–	35	ns
t_{off}	turn-off time		–	240	ns
t_s	storage time		–	200	ns
t_f	fall time		–	50	ns

Note

1. Pulse test: $t_p \leq 300$ μs; $\delta \leq 0.02$.

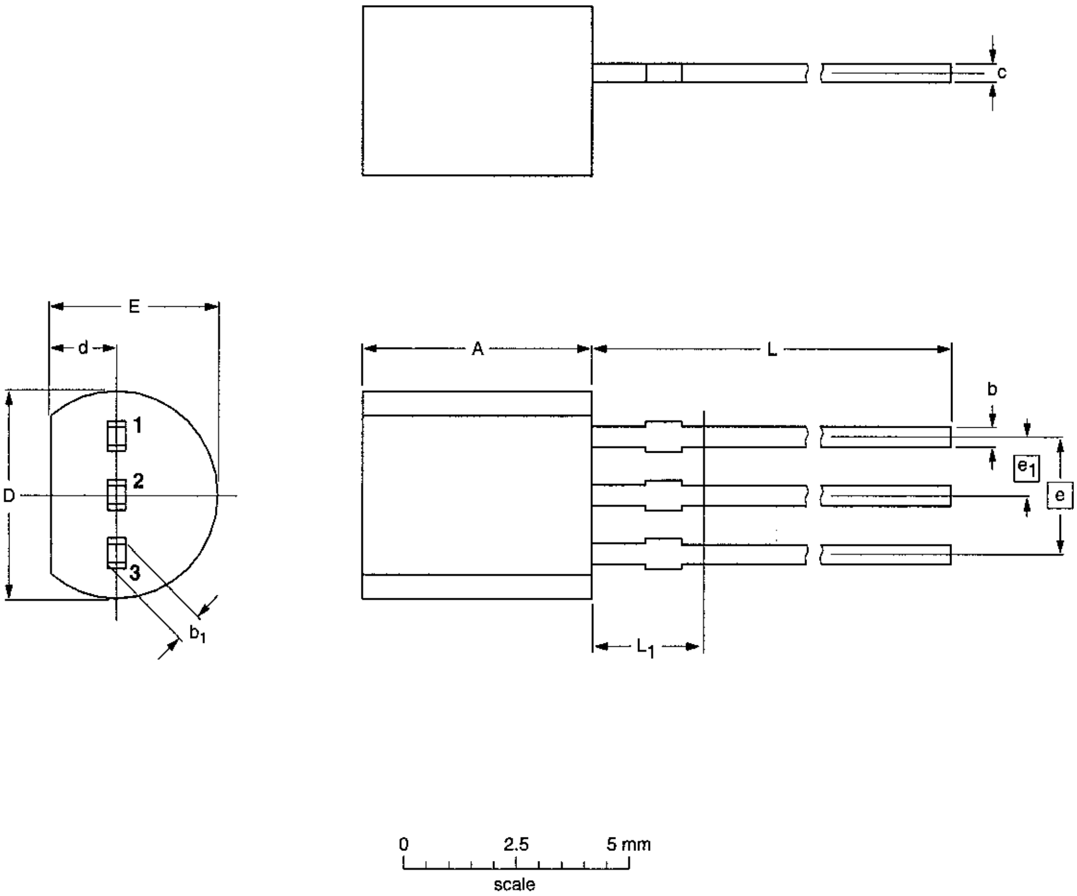


V_i = 5 V; T = 500 μs; t_p = 10 μs; $t_r = t_f \leq 3$ ns.
R1 = 56 Ω; R2 = 2.5 kΩ; R_B = 3.9 kΩ; R_C = 270 Ω.
V_{BB} = −1.9 V; V_{CC} = 3 V.
Oscilloscope input impedance Z_i = 50 Ω.

Fig.2 Test circuit for switching times.

PACKAGE OUTLINE

Plastic single-ended leaded (through hole) package; 3 leads **SOT54**



DIMENSIONS (mm are the original dimensions)

UNIT	A	b	b_1	c	D	d	E	e	e_1	L	L_1(1)
mm	5.2 5.0	0.48 0.40	0.66 0.56	0.45 0.40	4.8 4.4	1.7 1.4	4.2 3.6	2.54	1.27	14.5 12.7	2.5

Note

1. Terminal dimensions within this zone are uncontrolled to allow for flow of plastic and terminal irregularities.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT54		TO-92	SC-43			97-02-28

)EFINITIONS

Data sheet status	
Objective specification	This data sheet contains target or goal specifications for product development.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later.
Product specification	This data sheet contains final product specifications.
Limiting values	
Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.	
Application information	
Where application information is given, it is advisory and does not form part of the specification.	

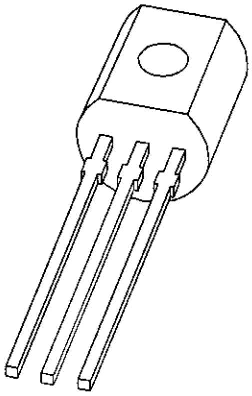
.IFE SUPPORT APPLICATIONS

ʾhese products are not designed for use in life support appliances, devices, or systems where malfunction of these ıroducts can reasonably be expected to result in personal injury. Philips customers using or selling these products for ıse in such applications do so at their own risk and agree to fully indemnify Philips for any damages resulting from such ɲproper use or sale.

APPENDIX F

(MPS3904 DATASHEET)

DATA SHEET



MPS3904
NPN switching transistor

Product specification
Supersedes data of 1997 Mar 03

1999 Apr 12

Philips
Semiconductors

PHILIPS

FEATURES

- Low current (max. 100 mA)
- Low voltage (max. 40 V).

APPLICATIONS

- General purpose switching and amplification.

DESCRIPTION

NPN transistor in a TO-92; SOT54 plastic package.
PNP complement: MPS3906.

PINNING

PIN	DESCRIPTION
1	collector
2	base
3	emitter

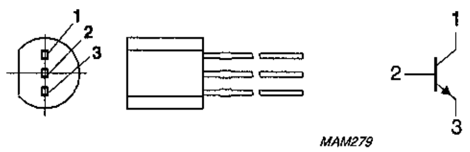


Fig.1 Simplified outline TO-92; SOT54 and symbol.

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter	–	60	V
V_{CEO}	collector-emitter voltage	open base	–	40	V
V_{EBO}	emitter-base voltage	open collector	–	6	V
I_C	collector current (DC)		–	100	mA
I_{CM}	peak collector current		–	200	mA
I_{BM}	peak base current		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	500	mW
T_{stg}	storage temperature		–65	+150	°C
T_j	junction temperature		–	150	°C
T_{amb}	operating ambient temperature		–65	+150	°C

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	note 1	250	K/W

Note

1. Transistor mounted on an FR4 printed-circuit board.

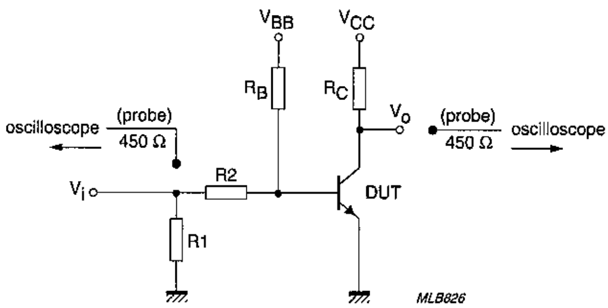
CHARACTERISTICS

T_{amb} = 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
I_{CBO}	collector cut-off current	$I_E = 0$; $V_{CB} = 30$ V	–	50	nA
I_{EBO}	emitter cut-off current	$I_C = 0$; $V_{EB} = 5$ V	–	50	nA
h_{FE}	DC current gain	$V_{CE} = 1$ V; note 1			
		$I_C = 0.1$ mA	40	–	
		$I_C = 1$ mA	70	–	
		$I_C = 10$ mA	100	300	
		$I_C = 50$ mA	60	–	
		$I_C = 100$ mA	30	–	
V_{CEsat}	collector-emitter saturation voltage	$I_C = 10$ mA; $I_B = 1$ mA; note 1	–	200	mV
		$I_C = 50$ mA; $I_B = 5$ mA; note 1	–	300	mV
V_{BEsat}	base-emitter saturation voltage	$I_C = 10$ mA; $I_B = 1$ mA; note 1	650	850	mV
		$I_C = 50$ mA; $I_B = 5$ mA; note 1	–	950	mV
C_c	collector capacitance	$I_E = i_e = 0$; $V_{CB} = 5$ V; 100 kHz ≤ f ≤ 1 MHz	–	5	pF
C_e	emitter capacitance	$I_C = i_c = 0$; $V_{EB} = 0.5$ V; 100 kHz ≤ f ≤ 1 MHz	–	15	pF
f_T	transition frequency	$I_C = 10$ mA; $V_{CE} = 20$ V; f = 100 MHz	180	–	MHz
F	noise figure	$I_C = 100$ μA; $V_{CE} = 5$ V; $R_S = 1$ kΩ; f = 10 Hz to 15.7 kHz	–	5	dB
Switching times (between 10% and 90% levels); (see Fig.2)					
t_{on}	turn-on time	$I_{Con} = 10$ mA; $I_{Bon} = 1$ mA; $I_{Boff} = -1$ mA; $V_{CC} = 3$ V; $V_{BB} = -1.9$ V	–	110	ns
t_d	delay time		–	50	ns
t_r	rise time		–	60	ns
t_{off}	turn-off time		–	1200	ns
t_s	storage time		–	1000	ns
t_f	fall time		–	200	ns

Note

1. Pulse test: $t_p \leq 300$ μs; δ = 0.02.

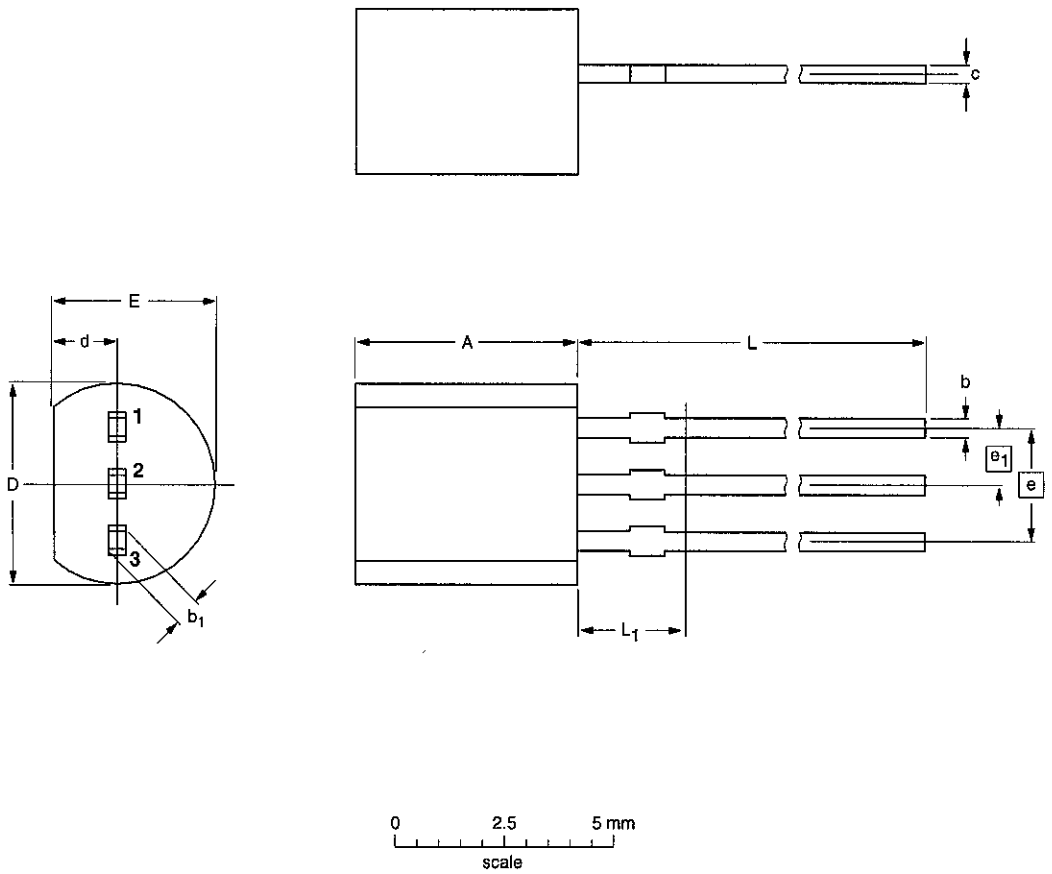


$V_i = 5$ V; $t_p \geq 4$ µs; $t_r = t_f \leq 3$ ns.
R1 = 56 Ω; R2 = 2.5 kΩ; $R_B = 3.9$ kΩ; $R_C = 270$ Ω.
Oscilloscope: input impedance $Z_i = 50$ Ω.

Fig.2 Test circuit for switching times.

PACKAGE OUTLINE

Plastic single-ended leaded (through hole) package; 3 leads **SOT54**

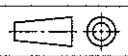


DIMENSIONS (mm are the original dimensions)

UNIT	A	b	b_1	c	D	d	E	e	e_1	L	L_1(1)
mm	5.2 5.0	0.48 0.40	0.66 0.56	0.45 0.40	4.8 4.4	1.7 1.4	4.2 3.6	2.54	1.27	14.5 12.7	2.5

Note

1. Terminal dimensions within this zone are uncontrolled to allow for flow of plastic and terminal irregularities.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT54		TO-92	SC-43			97-02-28

DEFINITIONS

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LIFE SUPPORT APPLICATIONS

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